Optimum detector to avoid interference in CDMA Communication Systems

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Abstract--
Now a days, Linear CDMA detectors are used in CDMA systems design. CDMA provides better capacity for voice and data communications than other commercial mobile technologies, allowing more subscribers to connect at any given time. In this paper, In order to solve the Multiple Access Interference (MAI) signal problem a method has been developed. SINR improvement is attained with no need for additional power-per-user investment at the transmitter since energy that is inherent in the CDMA system is utilized. The scheme introduced in this paper applies to the downlink of cellular PSK based CDMA systems. Theoretical analysis and comparative simulations show that significant performance improvement can be attained with the proposed technique.
Keywords: CDMA (Code Division Multiple Access), Multiple Access Interference (MAI), Adaptive Signal Processing, SINR (Signal to noise ratio) Decor relation, Downlink, phase-shift keying (PSK).

I. INTRODUCTION

THE performance of a code-division multiple-access (CDMA) system is affected with various forms of interference, which mainly derive from the multiple-access nature of the system and the frequency selectivity of the transmission medium. To reduce the complexity of the mobile units (MUs) of a CDMA communication system, the current trend is mitigating these system impediments at the base station (BS) prior to downlink transmission by use of pre-coding techniques. Various methods have been proposed by a number of researchers toward this end, following an initial idea proposed and published in the early 1970s that applies not only to CDMA but to generic communication systems as well. Esmailzadeh *et al* introduced a single-user pre-coding technique by transferring the Rake processing to the BS. This technique's main advantage is the simplification of the MU's architecture since simple matched filtering, which alleviates the need for channel estimation and removes a significant burden from the MU, is applied. This is done in the time-division duplex CDMA mode,

where uplink and downlink have highly correlated channel responses so that the downlink channel is accurately estimated during uplink detection at the BS. Although this technique outperforms the Rake receiver in the presence of multipath when nonorthogonal codes are used, it is mainly a single user method and, hence, does not efficiently combat multiple access interference (MAI). A multiuser transmitter pre-coding (TP) scheme is presented in, similar to the conventional receiver-based de-correlate–detector where the de-correlation procedure happens at the BS prior to transmission. In this paper, we introduce an idea for improving the performance of the TP and JT techniques analyzed. A pre-coding scheme parallel to that proposed, based on channel inversion pre-coding and applicable to interchannel interference (ICI) in multiple-input–multiple-output (MIMO) systems. The proposed method, the initial results of which were presented takes advantage of the constructive interference concept applicable in phase-shift keying (PSK) modulation, as will be analyzed in this paper.

2. Downlink Signal Model and Constructive MAI Definition for PSK Modulation

Consider the downlink transmission in a discrete-time synchronous frequency-selective CDMA system of K users, where the channels' path delays are assumed to be multiples of the chip interval with rectangular pulse shapes. All codes are assumed to have a fixed processing gain of L and a normalized energy of one. In addition, the multipath channel considered has P number of individual paths and a channel gain of unity. To simplify the notation and analysis in the following, we consider the case when the multipath delay spread is not large, and MAI from previous and next symbols can be neglected. Thus, bitwise processing can be adopted, which can easily be modeled in a discrete-time matrix format. A block wise processing analysis is given in Appendix I to cater for channels with long delay spread.

For the analysis here, we use the following definitions: $X^{(i)} = [X_1^{(i)} \quad X_2^{(i)} \; \ldots . X_k^{(i)}]$ is the 1 × k data vector, with the kth element of $X_k^{(i)}$ being the modulated symbol of the *k*th user for the *i*th symbol period; **A** =diag([a_1 a_2 a_3 ......a_k]) is the K × K diagonal matrix of amplitudes, with scalar a_k being the amplitude of the *k*th user; C=[$c^{(1)}$ $c^{(2)}$ ….. $c^{(k)}]^T$ is the K×L matrix containing the users' codes, with C= $[C_1^{(k)} \quad C_2^{(k)} \; \ldots . C_L^{(k)}]$ being the 1 × *L* code vector of the *K*th user, where the *l*th element $C_l^{(K)} \in \{-1/\sqrt{L}, 1/\sqrt{L}\}$ is the *l*th chip of the *k*th user's code sequence, and

$$\mathbf{H}^{(k)} = \begin{pmatrix} h_1^{(k)} & h_2^{(k)} & \cdots & h_P^{(k)} & & & 0 \\ & h_1^{(k)} & h_2^{(k)} & \cdots & h_P^{(k)} & & \\ & & \ddots & \ddots & & \ddots & \\ 0 & & & h_1^{(k)} & h_2^{(k)} & \cdots & h_P^{(k)} \end{pmatrix} \quad (1)$$

Employing Rake processing at the *u*th receiver, the decision symbol at the *i*th symbol period can be written as

$$d_u^{(i)} = r^{(iu)}.s^{(uu)H}$$

which is effectively the received signal multiplied by the code of user *u* corrupted by his downlink channel. In the operator $(.)^H$ represents the Hermitan transpose of a matrix. The output of the Rake receivers at all MUs can be combined in the 1 × *K* vector

$$d^{(i)} = X^{(i)} \cdot A \cdot R + \eta(i)$$

where **R** is the *K* × *K* cross correlation matrix of the multipath corrupted non-modulated signature waveforms. It is assumed that **R** is positive definite in order for the inverse to exist and defined as

$$\mathbf{R} = \begin{pmatrix} \rho_{11} & \rho_{12} & \cdots & \rho_{1K} \\ \rho_{21} & \rho_{22} & \cdots & \rho_{2K} \\ \vdots & \ddots & \ddots & \vdots \\ \rho_{K1} & \rho_{K2} & \cdots & \rho_{KK} \end{pmatrix} \quad (2)$$

Where the element on the *k*th row and *u*th column of the matrix is given by

$$\rho Ku = S^{(Ku)}.S^{(uu)H} = C^{(K)}.H^{(u)}.H^{(u)H}.C^{(u)H}.$$

It should be noted that, in the following, it is assumed that the codes and channel are normalized to unit energy so that ρuu=1. Evidently, orthogonality between users cannot be preserved using Walsh codes, as the resulting cross correlation of the codes viewed at the receiver is nonzero due to the channel distortion. The output of the *u*th Rake receiver of, which comprises the decision variable, can alternatively be written as

$$d_u^{(i)} = a_u x_u^{(i)} \rho uu + MAI_u^{(i)} + \eta_u^{(i)}$$

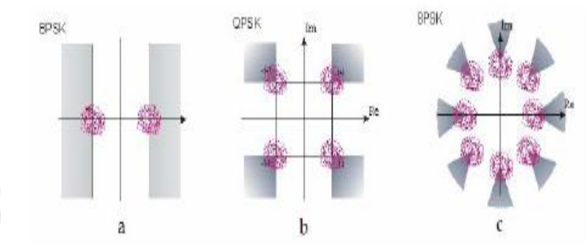

Fig1. The constellation diagrams of BPSK, QPSK and 8PSK modulation depicting possible noiseless received signals and the constructive MAI sectors.

3. Constructive MAI Derivation for Binary PSK (BPSK) Modulation.

In Fig. 1, possible noiseless receiver outputs for different PSK modulations are depicted, with the shadowed part denoting the constructive MAI sectors. For binary phase shift keying (BPSK) modulation, the desired user's symbol x(i) u ∈ {−1, +1}, and therefore, interference from a specific (*k*th) user is constructive when it has the same sign as the desired data *x*(*i*) *u* denoted by the shadowed part of the constellation in Fig. 1(a). The received symbols that satisfy this requirement are shown in green in the figure. For the user-to-user interference, this translates to be evaluated for all interfering users.

$$\text{Re}\,(a_u .x_u^{(i)}).\text{Re}\,(a_k.x^{(i)}_{k.pku}) > 0.$$

Therefore, to characterize the MAI, the left part of should be evaluated for all interfering users. Equation, shown at the bottom of the page, defines the cross-correlation matrix of the multipath affected signature waveforms, modulated by the data.
The criterion for constructive cumulative interference could be written as

$$\text{Sum}\,([\,M^{(i)} - \text{diag}(M^{(i)})]_u) > 0.$$

The preceding criterion translates differently to various higher order PSK constellations; however, the derivation of the constructive MAI expressions is a straightforward extension of the preceding criterion, and an extension to quadrature PSK (QPSK) and eight-state PSK (8PSK) appears in Appendix II. However, it should be noted that, as the order of PSK modulation increases, the decision thresholds become tighter, and the area of the constructive MAI diminishes, as shown in Fig. 1, which means that it is less likely to keep interference constructive. It should therefore be acknowledged that this could impose a limit on the performance improvement of the proposed method for higher order PSK. Nevertheless, the proposed technique—while still providing performance benefits for high-order PSK—is primarily useful at high-interference and low-SNR scenarios, where it is commonly acknowledged that low-order modulation is employed to boost

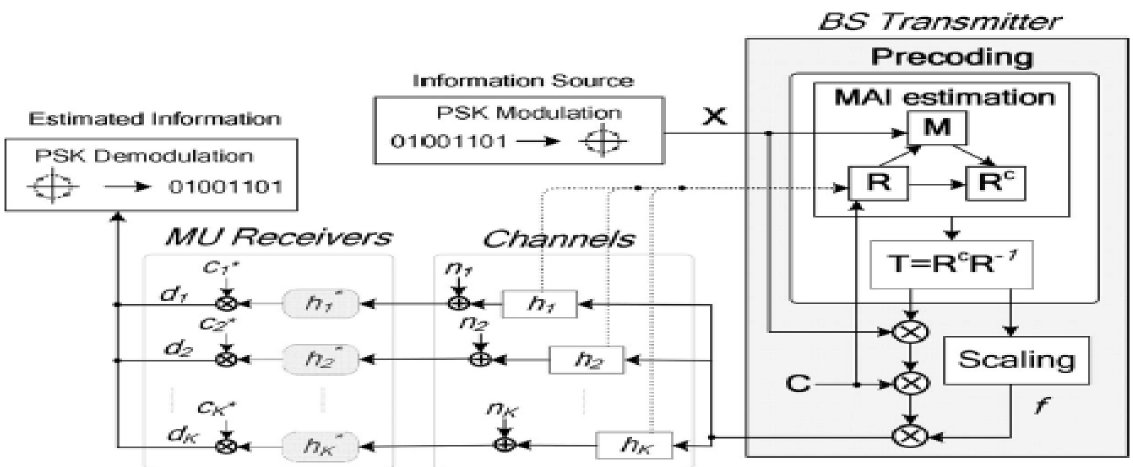

Fig.2. Proposed SP in the direct-sequence (DS)/CDMA downlink.

throughput. The performance benefits that are shown in Section VI are such that the proposed scheme provides a worthwhile alternative to conventional pre-coding.

$$\mathrm{MAI}_u^{(i)} = \sum_{k=1, k\neq u}^{K} a_k x_k^{(i)} \rho_{ku}.$$

For PSK modulation, the MAI is constructive when it adds to the desired user's signal energy, thus improving the effective signal-to interference-plus-noise ratio (SINR). Hence, the instantaneous effective SINR can be written as

$$\mathrm{SINR}_e = S + j_c / (j_d + N)$$

The average power of the instantaneous constructive and destructive MAI, respectively, and *Uc* and *Ud* denote the number of constructive and destructive interferers, respectively.

4. SELECTIVE PRECODING METHOD ANALYSIS

BPSK modulation and bitwise processing are assumed for simplicity. The extension to QPSK and 8PSK is straightforward with the use of the constructive criteria and in the following expressions. Additionally, the extension to block wise processing is also straightforward with the use of the cross-correlation matrices of that appear in Appendix I, in the following. A system employing TP is considered; however, transition to JT processing is simple, and the SP criteria shown here can identically be applied to both techniques. When pre-coding is applied, the transmitted $1 \times L$ vector is given as

$$G^{(i)} = f \cdot X^{(i)} \cdot A \cdot T \cdot C.$$

Here, $X^{(i)}$ and **A** are as previously presented, and **T** is the pre-coding matrix, excluding the spreading operation. f is the scaling factor that ensures that the average transmitted power per user is equal to that without pre-coding.

The signal vector and the cross-correlation matrix are given as

$$\mathbf{X} = [\, x_1 \quad x_2 \quad x_3 \quad x_4 \,]$$

$$\mathbf{R} = \begin{pmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} \\ \rho_{12} & 1 & \rho_{23} & \rho_{24} \\ \rho_{13} & \rho_{23} & 1 & \rho_{34} \\ \rho_{14} & \rho_{24} & \rho_{34} & 1 \end{pmatrix}.$$

The modulated cross-correlation matrix

$$\mathbf{M} = \begin{pmatrix} 1 & x_1x_2\rho_{12} & x_1x_3\rho_{13} & x_1x_4\rho_{14} \\ x_1x_2\rho_{12} & 1 & x_2x_3\rho_{23} & x_2x_4\rho_{24} \\ x_1x_3\rho_{13} & x_2x_3\rho_{23} & 1 & x_3x_4\rho_{34} \\ x_1x_4\rho_{14} & x_2x_4\rho_{24} & x_3x_4\rho_{34} & 1 \end{pmatrix}.$$

By observing the sum of each column of **M**, it can be derived whether the respective user will experience constructive or destructive MAI. Assuming that **X**=[1 1 1 1], $\rho_{12} = -0.3$, $\rho_{13} = -0.2$, $\rho_{14} = 0.4$, $\rho_{23} = 0.5$, $\rho_{24} = -0.1$, and $\rho_{34} = 0.2$, it can be seen that user 1 will experience destructive interference, whereas users 2–4 will benefit from constructive interference. The aforementioned example will be used throughout the following analysis of the three proposed precoding methods.

system, which further enhances the received SINR. Matrix **R***c* can be formed using three different criteria that are described here.

5. NUMERICAL AND SIMULATION RESULTS

BPSK, QPSK, and 8PSK modulations have been employed to investigate performance, and it is shown that, for all cases, the proposed scheme provides performance benefits. However, since SP mainly applies to high-interference scenarios where transmission is problematic and lower order modulation is commonly used to reduce the error rates, the focus is mainly on the BPSK and QPSK results.

For the multipath scenario, it was shown in that JT outperforms TP. For this reason, in Fig. 3, all three proposed techniques (SJT) are compared with JT for a Rayleigh fading channel of $P = 3$ paths occupied by $K = 12$ users. The SP method's superiority is evident as it yields an SNR gain up to 6 dB for SJT B for BPSK, 3 dB for QPSK, and 2 dB for 8PSK modulation. It should be noted that, for this frequency-selective fading case, the block wise processing , was employed and combined with SP.

For the presented example, this would yield

$$\mathbf{R}^c = \begin{pmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} \\ 0 & 1 & \rho_{23} & \rho_{24} \\ 0 & \rho_{23} & 1 & \rho_{34} \\ 0 & \rho_{24} & \rho_{34} & 1 \end{pmatrix}$$

This provides a noiseless matched filter output.

$$\mathbf{X}\mathbf{R}^c = [x_1 \quad x_2+\rho_{12}x_1+\rho_{23}x_3+\rho_{24}x_4x_3+\rho_{13}x_1 + \rho_{23}x_2+\rho_{34}x_4 \quad x_4+\rho_{14}x_1+\rho_{24}x_2+\rho_{34}x_3].$$

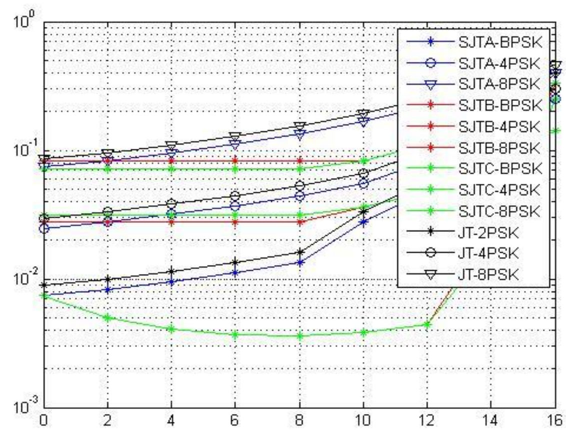

Fig 3: BER Versus K performance of conventional JT and SJT in aRayleigh channel of P = 3 for SNR =7dB;L = 16; orthogonal codes;and BPSK, QPSK, and 8PSK modulation.

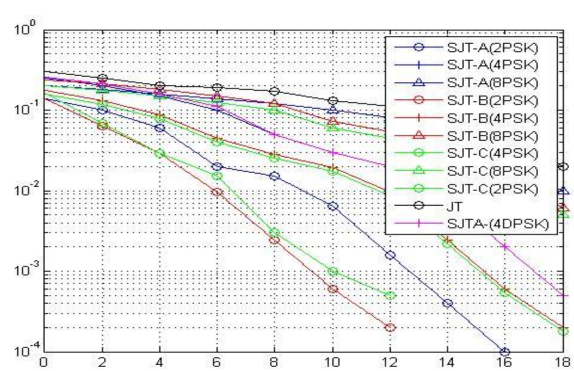

Fig 4: BER versus K performance of conventional JT and SJT precoding methods in a Rayleigh fading channel of P = 3 paths for K=12; L = 16; orthogonal codes; and BPSK, QPSK, and 8PSK modulation.

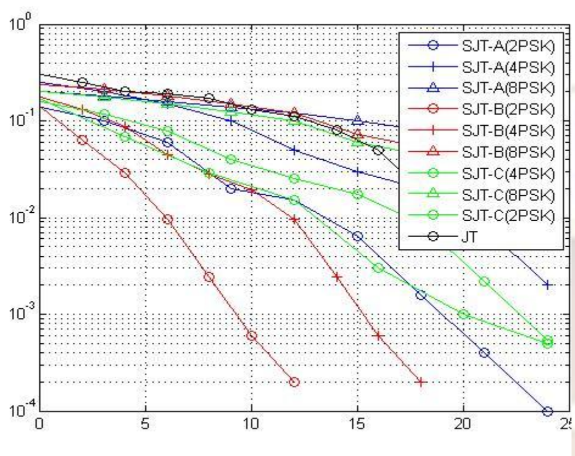

Fig 5: BER versus SNR performance of conventional JT and SJT pre-coding methods in a Rayleigh fading channel of P = 11 for K= 8users with unequal powers; L = 16; orthogonal codes; and BPSK, QPSK, and 8PSK modulation.

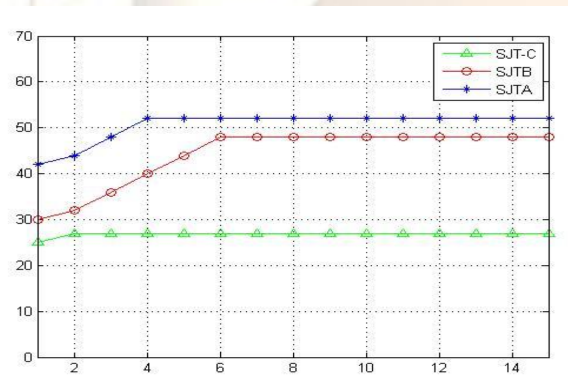

Fig 6: BER versus channel-gain- estimation error performance of conventional JT and SJT pre-coding methods in a Rayleigh fading channel of P = 11 for K = 8; L = 16; orthogonal codes; and BPSK, QPSK, and 8PSK modulation.

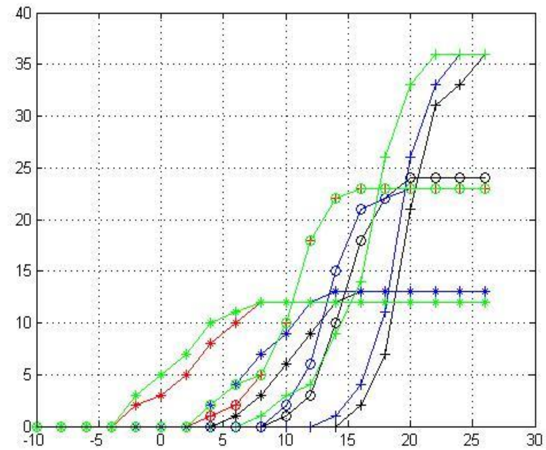

Fig 7: Average throughput versus SNR for JT and SJT in a Rayleigh fading channel of p = 11 for K = 12 users with unequal powers; L = 16; orthogonal codes; and BPSK, QPSK, 8PSK modulation.

7. CONCLUSION

In this paper, In order to solve the Multiple Access Interference (MAI) signal problem a method has been developed. SINR improvement is attained with no need for additional power - per – user investment at the transmitter since energy that is inherent in the CDMA system is utilized. The scheme introduced in this paper applies to the downlink of cellular phase-shift keying (PSK) - based CDMA systems. Theoretical analysis and comparative simulations show that significant performance improvement can be attained with the proposed technique. This Proposed work is to be implemented on MATLAB tool.

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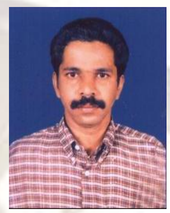

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