Performance Improvement and Complexity Reduction in MC-CDMA System using Coding Techniques

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Abstract: In this paper, partial pre-coding method has been developed to solve the Multiple Access Interference (MAI) and computational complexity problems. This is done by selectively pre-decorrelating users to destructive interference while allowing interference when it is expected to contribute to their signal. The resulting SNR improvement is achieved by making use of energy existent in the system so performance enhancement is attained without the need for increased transmitted power-per-user. The proposed technique applies to the downlink of cellular Code Division Multiple Access (CDMA) systems. Theoretical analysis and comparative simulations show that significant performance improvement and computational complexity can be attained with the proposed technique.

Keywords: CDMA, pre-coding, multiple access interference, multiuser channel.

I.INTRODUCTION

CDMA is a digital cellular technology. It uses spread spectrum technique. CDMA works on the principle of code multiplexing and its advanced version, named as W-CDMA is the candidate for future land mobile networks. Its detection techniques, broadly defined as multi-user detection, differ substantially from the conventional schemes. CDMA detector is used in CDMA systems design because the complexity of these detectors is linear with the number of system's users [1]. CDMA differs from the Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) in the sense that all users transmit across the entire frequency band (unlike FDMA) and many users can transmit simultaneously (unlike TDMA). CDMA doesn't design a specific frequency to each user. Each channel use fully available spectrum. Individual conversions encoded with pseudo random digital sequence [1].

Pre-coding techniques are gaining a prominent role in modern wireless communications as they offer the best potential for the simplification of Mobile Unites' (MU) receivers. In Multiple Carrier Code Division Multiple Access (MC-CDMA) these techniques are made more complexity-efficient since by use of guard intervals and Inter Symbol Interference (ISI) elimination there is no need for block wise processing. A variety of pre-decorrelating techniques for Direct Sequence CDMA (DS-CDMA) has been introduced but their application to MC-CDMA has not yet been thoroughly investigated. In [5] the authors propose transferring the channel equalization processing to the Base Station (BS) which yields the pre-equalization technique. This technique's main advantage is that the equalization processing is removed from the MU. However, without the use of Multi-User Detection (MUD) performance is poor in a multiuser scenario. The authors in [3] propose a system similar to the conventional receiver-based decorellator detector where the decorrelation procedure happens at the BS prior to transmission.

The Transmitter Precoding (TP) method presented in [4] investigated for DS-CDMA systems perform a complete orthogonalization amongst all users. This results in increased transmitted energy which calls for scaling of the signal to be transmitted. An improvement is attained by applying the Joint Transmission (JT) decorrelating procedure in [4]. This optimization – again presented for DS-CDMA leads to the use of a decorrelation scheme that also employs Pre-Rake processing [5]. This method offers both the benefits of pre-decorrelation as well as the advantages of Pre-Rake over the Rake technique as explained in [6]. Equivalently, in MC-CDMA, JT would apply pre-decorrelation processing on a system using pre-equalization while TP would utilize post-equalization. Both decorrelating methods introduced in [3-4] involve the inversion of a square matrix which imposes a significant computational burden when block wise processing is required. Evidently, these techniques could benefit in MC-CDMA from the fact that ISI and consequently MAI from symbols of adjacent symbol periods is eliminated and there is no need for block wise decorrelati on.In the next section, we present about the multiuser system description. In Section 3, analysis of pre-coding methods. Section 4 proposed pre-coding methods. Section 5 provides some simulation results on the performance compa rison of different pre-coding methods. The summary of the findings is given in conclusions in section 6.

II. MULTI-USER DETECTION

Spread spectrum has been very successfully used by the military for decades. DS-CDMA has a significant role in cellular and personal communications. Comparing to other multiple access schemes; DS-CDMA has been found to be attractive because of potential capacity increases over competing methods, robustness to multipath, soft capacity and soft handoff. There has been great interest in improving DS-CDMA detection through the use of multiuser detectors. Multiuser detection refers to the problem of detecting transmitted signals by considering all users. Initially, optimal multiuser detector, or the maximum likelihood sequence estimation detector was proposed by Verdu [15], this detector is much too complex for practical DS-CDMA systems.

There are two categories of the most proposed detectors: linear multiuser detectors and non-linear multiuser detectors. In linear multiuser detection, a linear mapping (transformation) is applied to the soft outputs of the conventional detector to produce a new set of outputs, which hopefully provide better performance. In non-linear detection, estimates of the interference are generated and subtracted out.

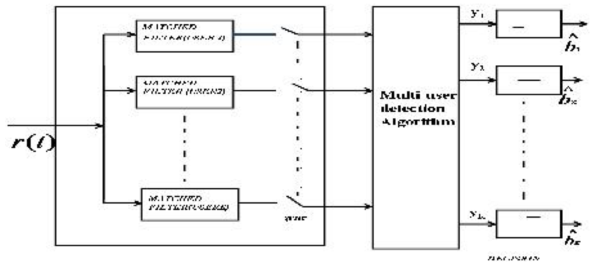

Fig.1: A typical multi-user detector

Figure-1 shows the general structure of multiuser detection systems. For detecting each K user's transmitted symbols from the received signal, which consists of a matched filter bank that converts the received continuous time signal to the discrete-time statistics sampled at chip rate without masking any transmitted information relevant to demodulation. This is followed by applying multiuser detection algorithm for optimality conditions to produce the soft output statistics [6]. The soft outputs are passed to the single user decoders. With the statistic $\{y_1, y_2, \ldots y_k\}$, at the output of the matched filter, an estimate for the transmitted bits $\{b_1, b_2, \ldots b_k\}$, that minimizes the probability of error can be found [6].

III. PRE-CODING METHOD ANALYSIS

Pre-coding techniques are gaining a prominent role in the downlink transmission of modern wireless communications as they offer an improved potential for the simplification of MU receivers. This type of processing at the transmitter requires the Channel State Information (CSI) at the transmitter. In order to be able to obtain CSI at the transmitter, the channel should be fixed (non-mobile) or approximately constant over a reasonably large time period. If CSI is available at the transmitter, the transmitted symbols, either for a single-user or for multiple users, can be partially separated by means of pre-equalization at the transmitter. In MC-CDMA these techniques are made more complexity-efficient since by use of guard intervals and ISI elimination there is no need for block wise processing. By means of pre-coding, the multiuser detection problem is reduced to decoupled single user detection problems. Normally, in synchronous multipath channels that are frequency non selective in nature, orthogonal signals can be employed. However, this requires code (signature waveform) management via a signalling channel [5].

III.1 Joint transmission

Joint Transmission (JT) as an example of downlink Coordinated Multi-Point (CoMP) transmission can improve the overall system performance, particularly the coverage of high throughput and cell-edge throughput. Many studies are related to JT in homogeneous network and based on full buffer traffic which is not a practical scenario. An improvement is attained by applying the JT decorrelating procedure. This optimization – again presented for DS-CDMA leads to the use of a decorrelation scheme that also employs Pre-Rake processing .This method offers both the benefits of pre-decorrelation as well as the advantages of Pre-Rake over the Rake technique. Equivalently, in MC-CDMA, JT would apply pre-decorrelation processing on a system using pre-equalization while TP would utilize post-equalization. The joint transmission are used to produce a vector of K-users' energies that will be multiplied by the inverse of KxK signatures' codes cross-correlation matrix [3].

III.2 Transmitter pre-coding

Transmitter pre-coding, as an alternative for combating multiple access interference in synchronous multiuser channels, e.g., on downlinks of code division multiple-access (CDMA) systems [4]. Transmitter pre-coding was originally proposed for additive white Gaussian noise (AWGN) channels and independently for flat fading channels. The goal of transmitter pre-coding is to facilitate a reduction of the signalling overhead. Transmitter pre-coding reduces a multiuser detection problem to decoupled single user detection problems and shifts the complexity from receivers to a common transmitter. The precoding performance is comparable to or better than, that of multiuser detection schemes of similar complexity and is considerably better than that of the conventional matched filter or the RAKE receiver without pre-coding. Transmitter pre-coding scheme removes MAI and multipath interference (MPI) at the BS is using an appropriate transformation of data signals. However, this scheme requires the rake processing at the Mobile Station (MS) to exploit multipath channels. The crucial assumption for pre-coding in multipath channels is that the transmitter has information about all channels between it and active receivers. This information can be obtained from receivers via feedback channels or can be estimated at the transmitter when a time-division duplex mode is employed, that is, when the same frequency band is employed for transmit and receive direction. Another important requirement is that the multipath channel is sufficiently slow, i.e., that it remains essentially constant over the block of pre-coded bits. Though, the length of the pre-coding block can be adjusted to match the channel dynamics. The practical applications of transmitter pre-coding can be found in wireless local loop, wireless LAN's and indoor communications in general, as well as any other wireless scenario where the pre-coding block size can be made sufficiently small so that the channel appears slow [7-8].

IV. PROPOSED SELECTIVE PRE-CODING METHODS

It should be clear so far, that the system can benefit from the existence of constructive interference. Consequently, there is no need for it to be removed by applying full pre-decorrelation. This is the main principle of the proposed system which is depicted in figure 2.

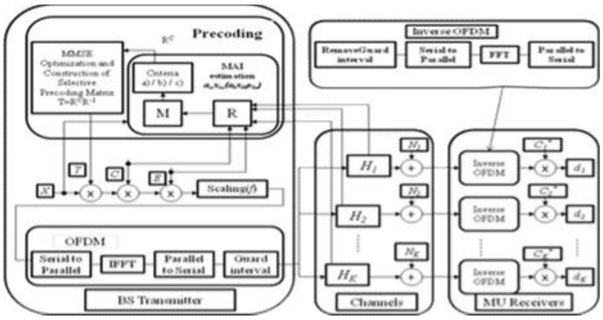

Fig.2: The proposed selective pre-coding in the MC-CDMA downlink

Using CSI, knowledge of all users' codes and data, readily available at the BS, and with the help of the interference to each user can be estimated at the BS prior to transmission. By observation of the matrix $\mathbf{M_i}$ the elements of the cross correlation matrix $\mathbf{R}$ to be removed via decorrelation can be determined. Hence the transmitted signal is given as:

$$s = f.\chi_i.AT.(C \circ E) \tag{1}$$

Where

$$f = \sqrt{\left(\sum_{k=1}^{N_d.K} a_k^2 \Big/ \sum_{k=1}^{N_d.K} a_k^2 T_{k,k} \right)} \tag{2}$$

f is the scaling factor and **T** is the pre-coding matrix excluding the spreading operation. Instead of **T** being derived by the MMSE optimization we propose the following MMSE optimization:

$$J = E_{x,n}\left\{ \left\| xAR^{C} - d \right\|^2 \right\} = E_{x,n}\left\{ \left\| xR^{C} - \left(xTR + n \right) \right\|^2 \right\} \tag{3}$$

where $\mathbf{R^c}$ is the constructive cross correlation matrix that contains the ρ_{uk} elements of $\mathbf{R}$ that yield constructive interference according to the observation of $\mathbf{M}i$ at every symbol period. Matrix $\mathbf{R^c}$ can be formed according to the three criteria that will be presented in the following sections. The solution to the above optimization is $\mathbf{T}=\mathbf{R^cR^{-1}}$. For TP and JT methods $\mathbf{R^c}=\mathbf{I}$ which derives full orthogonalization. Since for the proposed method the constructive cross correlation matrix $\mathbf{R^c} \neq \mathbf{I}$ contains elements of $\mathbf{R}$, selective pre-coding needs less manipulation. This is because the nonzero elements of $\mathbf{R^c}$ cancel out elements of $\mathbf{R^{-1}}$ and hence the elements of matrix $\mathbf{T}=\mathbf{R^cR^{-1}}$ are smaller than $\mathbf{T}=\mathbf{R^{-1}}$ for conventional pre-coding.

IV.1 Selective pre-coding method A (SJT A)

The simplest method would be to fully orthogonalized the users that experience destructive cumulative MAI and leave the users that expect constructive cumulative MAI correlated to interference. For the analysis here, we use the following dentitions:

$$X^{(i)} = \left[x_1^{(i)} x_2^{(i)} \cdots\cdots x_k^{(i)} \right] \tag{4}$$

$$A = \text{diag}\left(\left[a_1 a_2 \cdots\cdots a_k \right] \right) \tag{5}$$

$$C = \left[c_1^{(k)} c_2^{(k)} \cdots\cdots c_L^{(k)} \right]^T \tag{6}$$

$$C^{(k)} = \left[c_1^{(k)} c_2^{(k)} \cdots\cdots c_L^{(k)} \right] \tag{7}$$

Where

X is the data vector, with the k^{th} element $x_1^{(i)}$ being the modulated symbol of the kth user for the i^{th} symbol period; A is the K ×K diagonal matrix of amplitudes, with scalar a_k being the amplitude of the k^{th} user; C is the K × L matrix containing the users' codes. The output of the joint transmission at all MUs can be combined in the 1 × K vector

$$d^{i} = X^{i} \times A \times R + \eta^{(i)} \tag{8}$$

Where

R=cross correlation matrix of modulated signature waveform. It is assumed that R is positive definite in order for the inverse to exist and defined as

$$R^{c} = \begin{pmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} \\ 0 & 1 & \rho_{23} & \rho_{24} \\ 0 & \rho_{23} & 1 & \rho_{34} \\ 0 & \rho_{24} & \rho_{34} & 1 \end{pmatrix} \tag{9}$$

which provides a noiseless matched filter output as

$$X_R^{c} = \left[x_1x_2 + \rho_{12}x_1 + \rho_{23}x_3 + \rho_{23}x_2x_3 + \rho_{13}x_1 + \rho_{23}x_2 + \rho_{34}x_3x_4 + \rho_{14}x_1 + \rho_{24}x_2 + \rho_{34}x_3 \right] \tag{10}$$

It should be noted that, in the following, it is assumed that the codes and channel are normalized to unit energy so that ρ_{uu} =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.

IV.2 Selective pre-coding method B (SJT B)

An alternative to the preceding method would be to orthogonalize every user but only users that impose destructive interference to the useful signal at each symbol period. This would completely remove all destructive interference while allowing all constructive interference. For the analysis here, we use the following definitions:

$$X^{(i)} = \left[x_1^{(i)} x_2^{(i)} \cdots\cdots x_k^{(i)} \right] \tag{11}$$

$$A = \text{diag}\left(\left[a_1 a_2 \cdots\cdots a_k \right] \right) \tag{12}$$

$$C = \left[c_1^{(k)} c_2^{(k)} \cdots\cdots c_L^{(k)} \right]^T \tag{13}$$

$$C^{(k)} = \left[C_1^{(k)} C_2^{(k)} \cdots\cdots C_L^{(k)} \right] \tag{14}$$

Where

X is the data vector, with the kth element $x_1^{(i)}$ being the modulated symbol of the kth user for the ith symbol period; A is the K × K diagonal matrix of amplitudes, with scalar a_k being the amplitude of the k^{th} user; C is the K × L matrix containing the users' codes. The output of the joint transmission at all MUs can be combined in the 1 × K vector

$$d^{i} = X^{i} \times A \times R + \eta^{(i)} \tag{15}$$

Where

R=cross correlation matrix of modulated signature waveform. It is assumed that R is positive definite in order for the inverse to exist and defined as

$$R^{c}=\begin{pmatrix} 1 & 0 & 0 & \rho_{14} \\ 0 & 1 & \rho_{23} & 0 \\ 0 & \rho_{23} & 1 & \rho_{34} \\ \rho_{14} & 0 & \rho_{34} & 1 \end{pmatrix} \tag{16}$$

which provides a noiseless matched filter output as

$$X_R^{c}=\left[x_1+\rho_{14}x_4x_2+\rho_{23}x_3+\rho_{23}x_2+\rho_{34}x_4x_4+\rho_{14}x_1+\rho_{34}x_3\right] \tag{17}$$

It should be noted that, in the following, it is assumed that the codes and channel are normalized to unit energy so that ρ_{uu} =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.

IV.3 Selective pre-coding method C (SJT C)

Here, an optimization between the required scaling, the constructive interference held in the system, and complexity is attempted. This is done by orthogonalizing the users experiencing destructive cumulative MAI only to the users that impose destructive MAI on them while leaving the remaining users completely un-decorrelated. For the analysis here, we use the following definitions

$$X^{(i)}=\left[x_1^{(i)}x_2^{(i)}\cdots\cdots x_k^{(i)}\right] \tag{18}$$

$$A=\mathrm{diag}\left(\left[a_1a_2\cdots\cdots a_k\right]\right) \tag{19}$$

$$C=\left[c_1^{(k)}c_2^{(k)}\cdots\cdots c_L^{(k)}\right]^T \tag{20}$$

$$C^{(k)}=\left[c_1^{(k)}c_2^{(k)}\cdots\cdots c_L^{(k)}\right] \tag{21}$$

Where

X is the data vector, with the kth element $x_1^{(i)}$ being the modulated symbol of the kth user for the ith symbol period; A is the K × K diagonal matrix of amplitudes, with scalar a_k being the amplitude of the k^{th} user; C is the K × L matrix containing the users' codes. The output of the joint transmission at all MUs can be combined in the 1×K

$$d^{i}=X^{i}\times A\times R+\eta^{(i)} \tag{22}$$

Where

R=cross correlation matrix of modulated signature waveform. It is assumed that R is positive definite in order for the inverse to exist and defined as

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

which provides a noiseless matched filter output as

$$X_R^{c}=\left[x_1+\rho_{14}x_4x_2+\rho_{12}x_1+\rho_{23}x_3+\rho_{24}x_4x_3+\rho_{13}x_1+\rho_{23}x_2+\rho_{24}x_4x_3+\rho_{13}x_1+\rho_{23}x_2+\rho_{34}x_4x_4+\rho_{14}x_1+\rho_{24}x_2+\rho_{34}x_3\right] \tag{24}$$

It should be noted that, in the following, it is assumed that the codes and channel are normalized to unit energy so that ρ_{uu} =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.

V. SIMULATION RESULTS

In this work, we are using MATLAB tool. 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 Selective Precoding (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.

As for the spreading, orthogonal codes have been employed with a spreading gain of L =16. Multipath channel considered here is a complex-valued chip-spaced P-path decentralized Rayleigh frequency-selective fading with unity gain and equal average power per channel's path (uniform channel power profile). The effect of the channel-estimation errors on the system performance is also investigated. Unless stated otherwise, the average transmitted SNR = E_b/N_o per bit per user is considered in the performance results. In Fig.1 the BER versus SNR performance for the case of K=5 users in a multipath of P=3 paths is depicted for the JT method applied in MC-CDMA and the three proposed selective precoding (SJT) techniques. It can be seen that all three SJT methods outperform conventional precoding; due to the benefit from the existence of constructive MAI.In fig. 2 BER versus SNR performance for the same case is shown with QPSK modulation is shown. In fig. 3 BER versus SNR performance for the same case is shown with 8-PSK modulation. In all the performances of the MC-CDMA system SJT-C method is the best technique. In Fig. 4 the BER versus number of users K performance for SNR=7dB for the same multipath is shown. Since orthogonal codes are utilized, the performance is shown for P to K = L =16 users. For BPSK with SJT B, it can be that, up to a certain K, performance improves as the increase. This results from the fact that users are allowed to constructively interfere, which enhances the SINR and superimposes the effect of scaling; therefore, it surpasses single-user performance. The exploitation of constructive MAI leads to a significant user capacity improvement exceeding the factor of 2 for SJT B with BPSK at the BER $=10^{\wedge-2}$ point, compared with JT. Similar user capacity gains can be observed for the cases of QPSK and 8PSK modulation as well. It is evident that beyond a certain value of *K,* performance for all techniques severely deteriorates. In fig 5.the precoding methods of SJT B and SJT C it can be seen, that up to a certain K, performance improves as the users increase. In fig.6 it can be seen that selective precoding yields significant capacity improvement for all techniques as for the same BER level more users are allowed in the system. In figure7, complexity performance of the three partial precoding techniques is shown. The complexity evaluation is based on the number of elements removed from the cross correlation matrix. The performance show that the SJT-C is preferred method when complexity is required. When complexity is not required SJT-B is preferred.

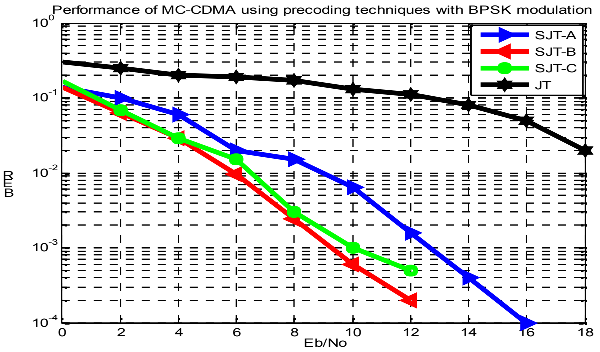

Fig.3:BER versus SNR performance of the three proposed SJT precoding methods in a Rayleigh fading channel of P = 3 paths for K =5; L =16; with BPSK modulation.

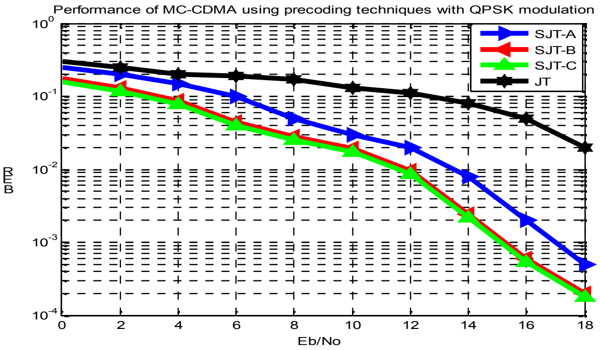

Fig.4:BER versus SNR performance of the three proposed SJT precoding methods in a Rayleigh fading channel of P = 3 paths for K =5; L =16; QPSK modulation.

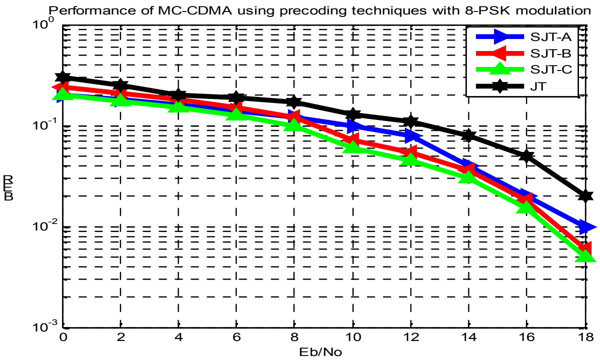

Fig.5:BER versus SNR performance of the three proposed SJT precoding methods in a Rayleigh fading channel of P = 3 paths for K =5; L =16; 8-PSK modulation.

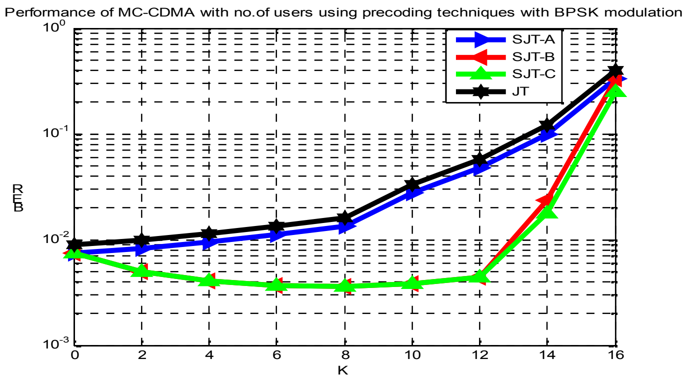

Fig.6:BER versus K performance of precoding techniques of P =3 for SNR =7 dB; L =16; orthogonal codes; BPSK modulation

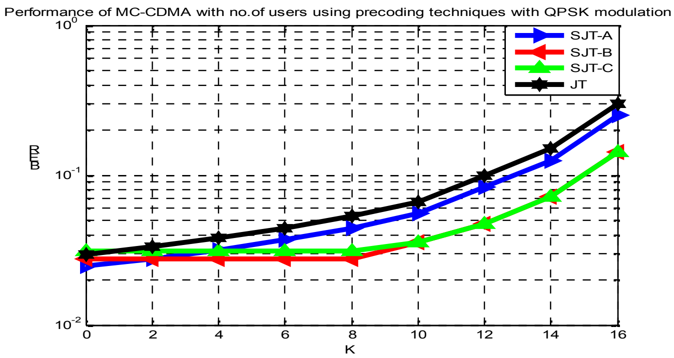

Fig.7:BER versus K performance of precoding techniques of P =3 for SNR =7 dB; L =16; orthogonal codes; QPSK modulation

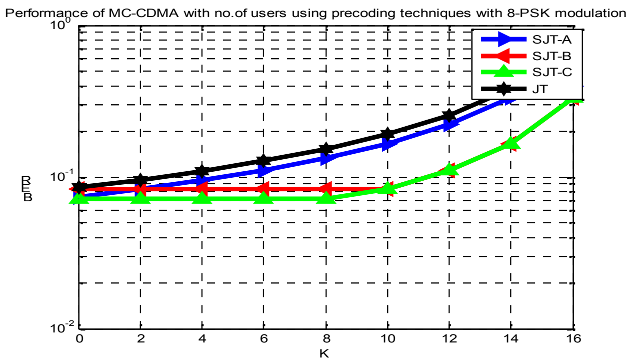

Fig.8:BER versus K performance of conventional JT and SJT in a Rayleigh channel of P =3 for SNR =7 dB; L =16; 8-PSK modulation

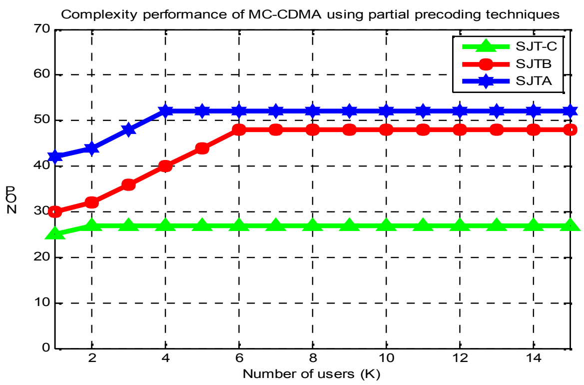

Fig.9:Decorrelating complexity of the three proposed SJT techniques for L =16, P =11, BPSK modulation, and SNR =7 dB

VI. CONCLUSION

A novel scheme joint transmission (JT) and SJT is proposed. which utilizes the knowledge of the channel impulse responses at the BS transmitter in such a way that at the receivers of the MS's channel estimators are no longer required. Consequently, the computational expense of the data detection is dramatically reduced. Three SP techniques have been introduced in the aim of optimizing between performance enhancement and complexity increase according to the requirements of the specific communication system. 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.

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