BER Performance Analysis of a FEC Encoded Multi-user MIMO MCCDMA Wireless Communication System

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Abstract

In this paper, we made a comprehensive study to evaluate the performance of a multi-user MIMO MCCDMA wireless communication system. The channel encoded spatially multiplexed MIMO MCCDMA system under investigation incorporates four linear signal detection schemes (Equalizers) such as Minimum Mean Square Error (MMSE), Zero Forcing (ZF), Sphere Decoding and Q-less QR Decomposition under BPSK, DPSK, QPSK and QAM digital modulations. It is anticipated from the numerical results that with the Q-less QR Decomposition based signal detection scheme, the multi-user MIMO MCCDMA system outperforms in BPSK digital modulation under AWGN and Raleigh fading channels .In Zero Forcing detection scheme, the system shows comparatively worst performance. It has been observed from the present study that the system performance deteriorates with increase in order of digital modulation and noise power as compared to signal power.

Keywords: *MCCDMA, Signal detection scheme, Bit Error rate, AWGN and Raleigh fading channels.*

1. Introduction

With the growing need for technological innovations in wireless communications, it has become a challenging task to design next generation (4G) Internet Protocol (IP)-based heterogeneous multi-antenna supported robust communication systems adopting various digital modulation schemes to ensure a crystal clear voice conversation, live video transmission and high speed internet connectivity. To meet up such challenges, a considerable amount of research is being going on worldwide to materialize the ever increasing wish of mankind using the constrained resources.

Orthogonal Frequency Division Multiplexing (OFDM) has emerged as a successful air-interface multicarrier digital modulation technique advocated by many European standards, such as Digital Audio Broadcasting (DAB), Digital Video Broadcasting for Terrestrial television (DVB-T), Digital Video Broadcasting for Handheld terminals (DVB-H), Wireless Local Area Networks (WLANs) and Broadband Radio Access Networks (BRANs). Code Division Multiple Access (CDMA) technique is widely used in current Third Generation (3G) wireless communication systems providing higher data rate i.e. 64kbps –2Mbps as compared to 9.6kbps – 14.4kbps used in 2G systems. Multicarrier Code DivisionMultiple Access (MC-CDMA) exploits the benefits of both OFDM and CDMA technologies and is expected to be a possible candidate for

Fourth eneration (4G) wireless communication systems that demand higher data rate for voice and data transmissions **[1, 2].** The multicarrier (MC) technique has grown an important alternative for wireless indoor communications. One large advantage of this technology is its robustness in case of multipath propagation. As the MC-CDMA takes advantage of both OFDM and CDMA and it makes an efficient transmission system by spreading the input data symbols with spreading codes in frequency domain. It uses a number of narrowband orthogonal subcarriers with symbol duration longer than the delay spread. This makes it unlikely for all the sub carriers to be affected by the same deep fades of the channel at the same time thereby improving performance **[3].** In the present FEC encoded multi user MIMO MCCDMA wireless communication system, each of the four users is assigned with a set of orthogonal Walsh-Hadamard codes for respective data transmission.

2. Mathematical Model

In our presently considered spatially multiplexed MIMO MCCDMA wireless communication system, Alamouti's G_2 Space time block coding and various signal detection schemes (previously used and a newly proposed) have been implemented. A brief description is given below.

2.1 Alamouti's G_2 Space Time Block Coding Scheme

In 1998, Alamouti presented a simple two-branch transmit diversity scheme. Antenna diversity used in Space-time Block Coding scheme has been recognized as practically effective technique for reducing the effect of multipath fading. In precoding and transmission sequence under Alamouti's G_2 Space time block coding scheme, we assume that two digitally modulated signals are simultaneously transmitted from the two antennas at a given symbol period. During the first symbol period, the signal transmitted from the first antenna is denoted by $\mathbf{s_1}$ and from the second antenna by $\mathbf{s_2}$. During the next symbol period, the signal $\mathbf{-s_2^*}$ is transmitted from the first antenna and the $\mathbf{s_1^*}$ is transmitted from the second antenna where * is indicative of complex conjugate operation **[4].** If H is a channel matrix with its (j,i)th entry $\mathbf{h_{ji}}$ for the channel gain between the ith transmitting antenna and the jth receiving antenna , j=1,2 and i= 1,2., we can write:

$$\mathbf{H} = \begin{bmatrix} \mathbf{h}_{11} & \mathbf{h}_{12} \\ \mathbf{h}_{21} & \mathbf{h}_{22} \end{bmatrix} \quad \mathbf{(1)}$$

In first symbol period, the signal received at the first and second receiving antennas are given by:

$$\left.\begin{aligned} y_{1first} &= h_{11}s_1 + n_{11} + h_{12}s_2 + n_{12} \\ y_{1second} &= h_{21}s_1 + n_{21} + h_{22}s_2 + n_{22} \end{aligned}\right| \quad \mathbf{(2)}$$

In second symbol period, the signal received at the first and second receiving antennas are given by:

$$\left.\begin{aligned} y_{2first} &= -h_{11}s_2^* + n_{11} + h_{12}s_1^* + n_{12} \\ y_{2second} &= -h_{21}s_2^* + n_{21} + h_{22}s_1^* + n_{22} \end{aligned}\right| \quad \mathbf{(3)}$$

where, n_{11} and $n_{12,}$ n_{21} and n_{22} are the complex random variables representing receiver noise and interference in the channels assigned between transmitting and receiving antennas. Using signal detection scheme, the precoded and OFDM block wise digitally modulated symbols transmitted from each of the two antennas are detected

2.2 Signal Detection Schemes

Linear signal detection scheme treats all transmitted signals as interferences except for the desired stream from the target transmitting antenna. The spatially –multiplexed transmitted user data (digitally modulated signal) in OFDM block and the corresponding received signals are represented by $\mathbf{x=[x_1, x_2]^T}$ and $\mathbf{y=[y_1,y_2]^T}$ respectively, where $\mathbf{x_i}$ and $\mathbf{y_i}$ denote the transmit signal from ith transmitting antenna and the received signal at the jth receiving antenna respectively. Let $\mathbf{n_j}$ denote the white Gaussian noise with a variance of $\boldsymbol{\sigma_n}^2$ at the jth receiving antenna and $\mathbf{h_i}$ denote the ith column vector of the channel matrix $\mathbf{H}$. The received signal $\mathbf{y}$ for the 2 x 2 MIMO MCCDMA system can be represented as

$$y = Hx + \mathbf{n} = h_1\mathbf{x}_1 + h_2\mathbf{x}_2 \tag{4}$$

where, $\mathbf{n} = [n_1, n_{2R}]^T$

As the interference signals from other transmitting antennas are minimized or nullified in the course of detecting the desired signal from the target transmitting antenna, the detected desired signal from the transmitting antenna with inverting channel effect by a weight matrix W is given by

$$\tilde{\mathbf{x}} = [\tilde{\mathbf{x}}_1, \tilde{\mathbf{x}}_2]^{\mathbf{T}} = \mathbf{Wy} \tag{5}$$

In Minimum mean square error (MMSE) scheme, the MMSE weight matrix is given by

$$\mathbf{W_{MMSE}} = (\mathbf{H^H H} + \sigma_{\mathbf{n}}{}^2\mathbf{I})^{-1}\mathbf{H^H} \tag{6}$$

and the detected desired signal from the transmitting antenna is given by

$$\tilde{\mathbf{x}}_{\mathbf{MMSE}} = \mathbf{W_{MMSE}\,y} \tag{7}$$

In Zero-Forcing (ZF) scheme, the ZF weight matrix is given by

$$\mathbf{W_{ZF}} = (\mathbf{H^H H})^{-1}\mathbf{H^H} \tag{8}$$

and the detected desired signal from the transmitting antenna is given by

$$\tilde{\mathbf{x}}_{\mathbf{ZF}} = \mathbf{W_{ZF}\,y} \tag{9}$$

In Sphere Decoding (SD) scheme intends to find the transmitted signal vector with minimum ML metric, that is, to find the ML solution vector. However, it considers only a small set of vectors within a given sphere rather than all possible transmitted signal vectors. SD adjusts the sphere radius until there exists a single vector (ML solution vector) within a sphere. It increases the radius when there exists no vector within a sphere and decreases the radius when there exist multiple vectors within the sphere. Let y_{jR} and y_{jI} denote the real and imaginary parts of the received signal at the jth receive antenna, that is, $y_{jR=}$ Re{y_j} and $y_{jI=}$ Im{$y_{j\,\}}$. Similarly, the input signal x_i from the ith antenna can be represented by x_{iR} = Re{x_i} and x_{iI} = Im{x_i}. The received signal can be expressed in terms of its real and imaginary parts as follows:

$$\begin{bmatrix} \mathbf{y}_{1R} + \mathbf{j}\mathbf{y}_{1I} \\ \mathbf{y}_{2R} + \mathbf{j}\mathbf{y}_{2I} \end{bmatrix} = \begin{bmatrix} \mathbf{h}_{11R} + \mathbf{j}\mathbf{h}_{11I} & \mathbf{h}_{12R} + \mathbf{j}\mathbf{h}_{12I} \\ \mathbf{h}_{21R} + \mathbf{j}\mathbf{h}_{21I} & \mathbf{h}_{22R} + \mathbf{j}\mathbf{h}_{22I} \end{bmatrix} \begin{bmatrix} \mathbf{x}_{1R} + \mathbf{j}\mathbf{x}_{1I} \\ \mathbf{x}_{2R} + \mathbf{j}\mathbf{x}_{2I} \end{bmatrix} + \begin{bmatrix} \mathbf{n}_{1R} + \mathbf{j}\mathbf{n}_{1I} \\ \mathbf{n}_{2R} + \mathbf{j}\mathbf{n}_{2I} \end{bmatrix} \qquad \textbf{(10)}$$

where, h_{ij} =Re{ h_{ij}}, h_{ij} =Im{h_{ij}}, n_i =Re{n_i}. The real and imaginary part of Equation **(10)** can be respectively expressed as:

$$\begin{bmatrix} \mathbf{y}_{1R} \\ \mathbf{y}_{2R} \end{bmatrix} = \begin{bmatrix} \mathbf{h}_{11R} & \mathbf{h}_{12R} \\ \mathbf{h}_{21R} & \mathbf{h}_{22R} \end{bmatrix} \begin{bmatrix} \mathbf{x}_{1R} \\ \mathbf{x}_{2R} \end{bmatrix} - \begin{bmatrix} \mathbf{h}_{11I} & \mathbf{h}_{12I} \\ \mathbf{h}_{21I} & \mathbf{h}_{22I} \end{bmatrix} \begin{bmatrix} \mathbf{x}_{1I} \\ \mathbf{x}_{2I} \end{bmatrix} + \begin{bmatrix} \mathbf{n}_{1R} \\ \mathbf{n}_{2R} \end{bmatrix}$$

$$= \begin{bmatrix} \mathbf{h}_{11R} & \mathbf{h}_{12R} & -\mathbf{h}_{11I} & -\mathbf{h}_{12I} \\ \mathbf{h}_{21R} & \mathbf{h}_{22R} & -\mathbf{h}_{21I} & -\mathbf{h}_{22I} \end{bmatrix} \begin{bmatrix} \mathbf{x}_{1R} \\ \mathbf{x}_{2R} \\ \mathbf{x}_{1I} \\ \mathbf{x}_{2I} \end{bmatrix} + \begin{bmatrix} \mathbf{n}_{1R} \\ \mathbf{n}_{2R} \end{bmatrix} \qquad \textbf{(11)}$$

and

$$\begin{bmatrix} \mathbf{y}_{1I} \\ \mathbf{y}_{2I} \end{bmatrix} = \begin{bmatrix} \mathbf{h}_{11I} & \mathbf{h}_{12I} & \mathbf{h}_{11R} & \mathbf{h}_{12R} \\ \mathbf{h}_{21I} & \mathbf{h}_{22I} & \mathbf{h}_{21R} & \mathbf{h}_{22R} \end{bmatrix} \begin{bmatrix} \mathbf{x}_{1R} \\ \mathbf{x}_{2R} \\ \mathbf{x}_{1I} \\ \mathbf{x}_{2I} \end{bmatrix} + \begin{bmatrix} \mathbf{n}_{1I} \\ \mathbf{n}_{2I} \end{bmatrix} \qquad \textbf{(12)}$$

The Equations **(11)** and **(12)** can be combined to yield the following expression:

$$\underbrace{\begin{bmatrix} \mathbf{y}_{1R} \\ \mathbf{y}_{2R} \\ \mathbf{y}_{1I} \\ \mathbf{y}_{2I} \end{bmatrix}}_{\bar{y}} = \underbrace{\begin{bmatrix} \mathbf{h}_{11R} & \mathbf{h}_{12R} & -\mathbf{h}_{11I} & -\mathbf{h}_{12I} \\ \mathbf{h}_{21R} & \mathbf{h}_{22R} & -\mathbf{h}_{21I} & -\mathbf{h}_{22I} \\ \mathbf{h}_{11I} & \mathbf{h}_{12I} & \mathbf{h}_{11R} & \mathbf{h}_{12R} \\ \mathbf{h}_{21I} & \mathbf{h}_{22I} & \mathbf{h}_{21R} & \mathbf{h}_{22R} \end{bmatrix}}_{\bar{H}} \underbrace{\begin{bmatrix} \mathbf{x}_{1R} \\ \mathbf{x}_{2R} \\ \mathbf{x}_{1I} \\ \mathbf{x}_{2I} \end{bmatrix}}_{\bar{x}} + \underbrace{\begin{bmatrix} \mathbf{n}_{1R} \\ \mathbf{n}_{2R} \\ \mathbf{n}_{1I} \\ \mathbf{n}_{2I} \end{bmatrix}}_{\bar{n}} \qquad \textbf{(13)}$$

From Equation **(13)**, the detected desired signal from the transmitting antenna can be obtained using the following relation **[5]**:

$$\bar{\mathbf{x}} = (\bar{\mathbf{H}}^{\mathbf{H}}\bar{\mathbf{H}})^{-1}\bar{\mathbf{H}}^{\mathbf{H}}\bar{\mathbf{y}} \qquad \textbf{(14)}$$

With Q-less QR Decomposition scheme, the detected desired signal $\tilde{\mathbf{x}}$ from the transmitting antenna can be found based on the least squares approximate solution to $\tilde{\mathbf{H}} * \tilde{\mathbf{x}} = \tilde{\mathbf{y}}$ where, $\tilde{\mathbf{H}}$ and $\tilde{\mathbf{y}}$ are the channel matrix and received signal respectively. From $\tilde{\mathbf{H}}$ channel matrix, an upper triangular matrix $\tilde{\mathbf{R}}$ of the same dimension as $\tilde{\mathbf{H}}$ is estimated and using the following steps, the detected desired signal $\tilde{\mathbf{x}}$ is computed **[6].**

$$\begin{aligned} \tilde{\mathbf{x}} &= \tilde{\mathbf{R}} \backslash (\tilde{\mathbf{R}}^{\mathbf{H}} \backslash (\tilde{\mathbf{H}}^{\mathbf{H}} * \tilde{\mathbf{y}})) \\ \tilde{\mathbf{r}} &= \tilde{\mathbf{y}} - \tilde{\mathbf{H}} * \tilde{\mathbf{x}} \\ \tilde{\mathbf{e}} &= \tilde{\mathbf{R}} \backslash (\tilde{\mathbf{R}}^{\mathbf{H}} \backslash (\tilde{\mathbf{H}}^{\mathbf{H}} * \tilde{\mathbf{r}})) \\ \tilde{\mathbf{x}} &= \tilde{\mathbf{x}} + \tilde{\mathbf{e}} \end{aligned} \qquad \textbf{(15)}$$

2.3. Communication System Model

A simulated multi-user 2 x 2 MIMO MCCDMA wireless communication system as depicted in Figure 1 utilizes ½-rated Convolutional channel coding scheme. In such a communication system, four users are simultaneously transmitting their synthetically generated information bits.

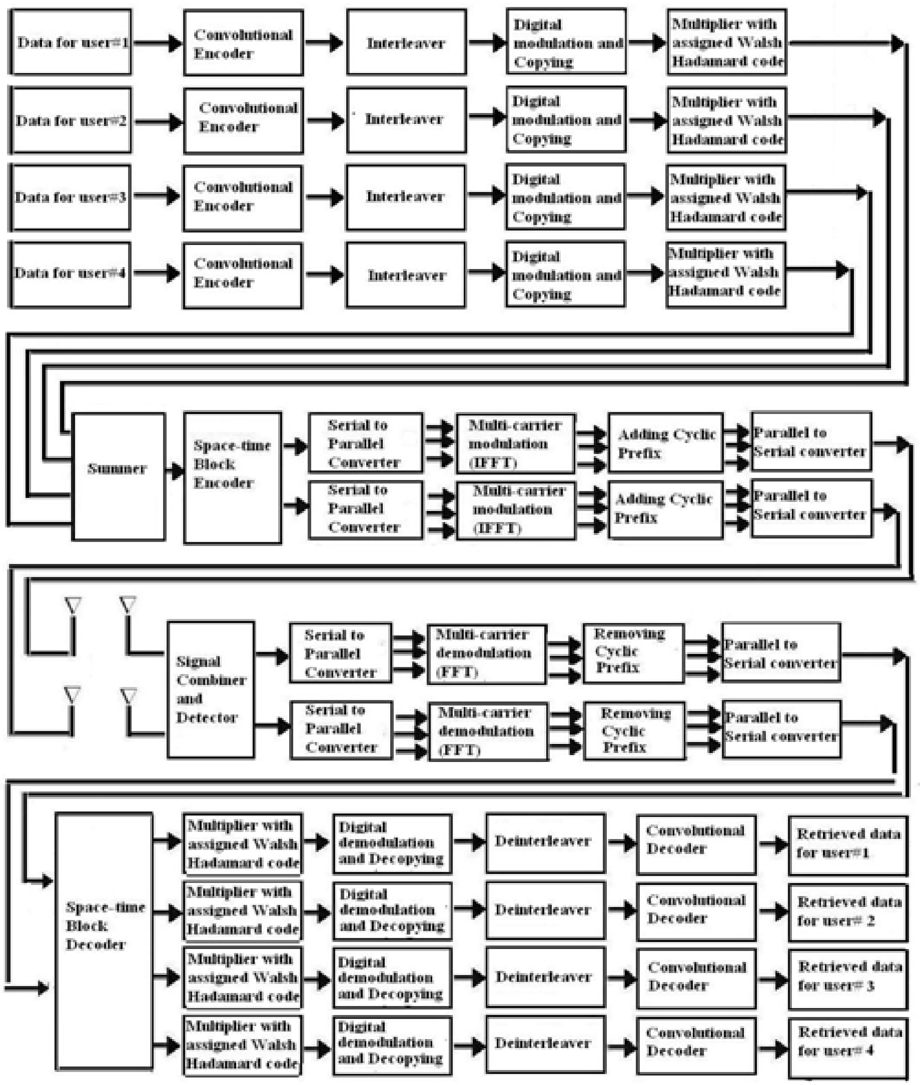

Figure 1. Block Diagram of a Multi-user MIMO MCCDMA Wireless Communication System

The transmitted bits of each individual user are channel encoded and interleaved for minimization of burst errors. The interleaved bits are digitally modulated using various types of digital modulations such as Binary Phase Shift Keying (BPSK), Differential Phase Shift Keying (DPSK), Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude modulation (QAM) and the number of digitally modulated symbols is increased (copied) eight times (as the processing gain/ sequence length of the Walsh–Hadamard (WH) transformed orthogonal codes is eight) and subsequently multiplied with Walsh–Hadamard codes assigned for individual user. The Walsh–Hadamard and Convolutionally encoded interleaved digitally modulated symbols are summed up and fed into Space-time block encoder for processing with implemented philosophy of Alamouti's G_2 Space- time block coding scheme **[7].** The output of the Space- time block encoder are sent up into two serial to parallel converter. The serial to parallely (S/P) converted complex data symbols are fed into each of the two OFDM modulator with 1024 sub carriers which performs an IFFT on each OFDM block of length 1024 followed by a parallel –to- serial conversion. A cyclic prefix (CP) of length L_{cp} (0.1*1024) containing a copy of the last L_{cp} samples of the parallel –to- serial converted output of the 1024-point IFFT is then prepended. The CP is essentially a guard interval which serves to eliminate interference between OFDM symbols. However, the resulting OFDM symbols of length 1024+ Lcp are lunched from the two transmitting antenna. In receiving section, all the transmitted signals are detected with linear signal detection schemes and the detected signals are subsequently sent up to the serial to parallel (S/P) converter and fed into OFDM demodulator which performs FFT operation on each OFDM block. The FFT operated OFDM blocked signal are processed with cyclic prefix removing scheme and are undergone from parallel to serial conversion and are fed into Space time block decoder. Its output is multiplied with assigned Walsh–Hadamard codes in four individual sections. In each of the four sections, the complex symbols are digitally demodulated, decopied, deinterleaved and convolutionally decoded to recover the transmitted data for each of the four users **[8, 9].**

3. Results and Discussion

We have conducted computer simulations to evaluate the BER performance of the multi user MIMO MCCDMA wireless communication system based on the parameters given in Table 1. It is assumed that the channel state information (CSI) is available at the receiver and the fading process is approximately constant during one OFDM block length. The graphical illustrations presented in Figure 2 through Figure 5 show system performance comparison with implementation of MMSE, ZF, Sphere Decoding and Q-less QR Decomposition based signal detection schemes under various low order digital modulations. In all cases, the system outperforms in BPSK and shows worst performance in QPSK digital modulations. The BER performance difference is quite obvious in lower SNR areas and the system's BER declines with increase in SNR values. In Figure 2, it is noticeable that for a typically assumed SNR value of 3 dB, the BER values are 0.0128 and 0.2263 in case of BPSK and QPSK digital modulations viz., the system achieves a substantial gain of 12.47 dB in BPSK as compared to QPSK. In Figure 3, the BER values in case of BPSK and QPSK are 0.0150 and 0.2446 for a 3dB SNR value which is indicative of an enhancement of system performance by 12.12 dB. Similarly, in Figure 4

Table 1: Summary of the Simulated Model Parameters

No. of bits used for four users	1024
No. of Transmitting/ Receiving antenna	2
Channel Coding	½-rated Convolutional Encoder
Modulation	BPSK, DPSK, QPSK and QAM
No. of OFDM sub-carriers	1024
Spreading Code	Walsh-Hadamard
Signal Detection Scheme	Mean square error (MMSE), Zero-forcing (ZF), Sphere decoding (SD) and Q-less QR decomposition
CP length	103 symbols
Channel	AWGN and Rayleigh
Signal to noise ratio, SNR	0 to10 dB

with Sphere Decoding signal detection scheme, the system achieves a gain of 12.47 dB at SNR value of 3 dB. In Figure 5, the BER simulation graphs are depicted under implementation of Q-less QR Decomposition based signal detection scheme. At a SNR value of 3dB, an improvement of the system performance is observed in BPSK by16.63 dB as compared to QPSK. Figure 6 confirms the most satisfactory performance of the system with deployment of the Q-less QR Decomposition based signal detection scheme. In Figure 7, the transmitted and retrieved bits for four users at low SNR value of 3dB have been represented. The estimated bit error rate is 0.0033 and the retrieving capability of the multi user MIMO OFDMA wireless communication system is found to be quite satisfactory under BPSK and Q-less QR decomposition based signal detection scheme

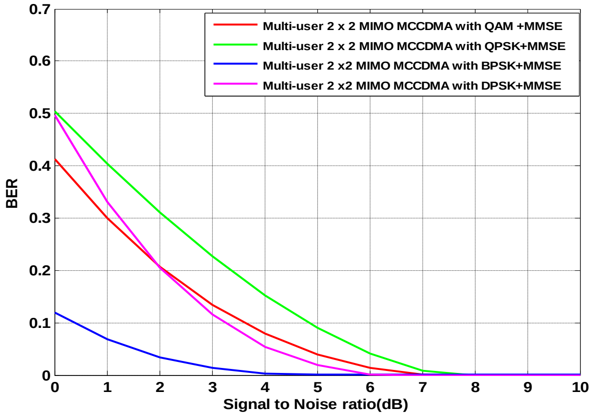

Figure 2. BER Performance for multi-user MIMO MCCDMA wireless communication system with Implementation of Minimum Mean Square Error(MMSE) signal detection scheme under different digital modulations.

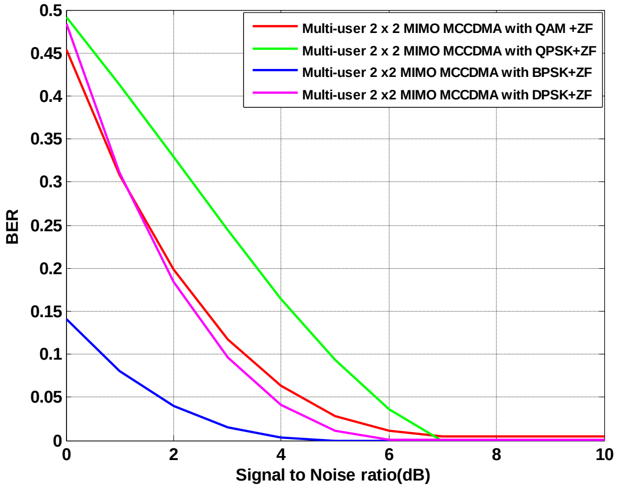

Figure 3. BER Performance for multi-user MIMO MCCDMA wireless communication system with implementation of Zero-Forcing(ZF) signal detection scheme under different digital modulations.

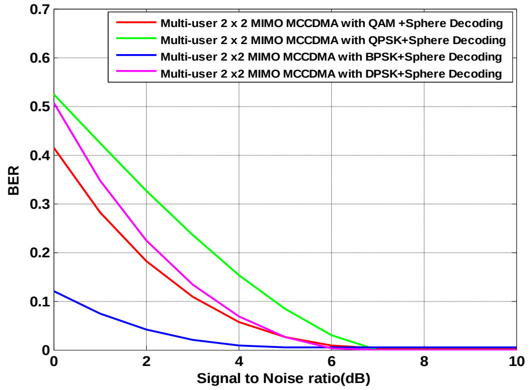

Figure 4. BER Performance for multi-user MIMO MCCDMA wireless communication system with implementation of Sphere Decoding (SD) signal detection scheme under different digital modulations.

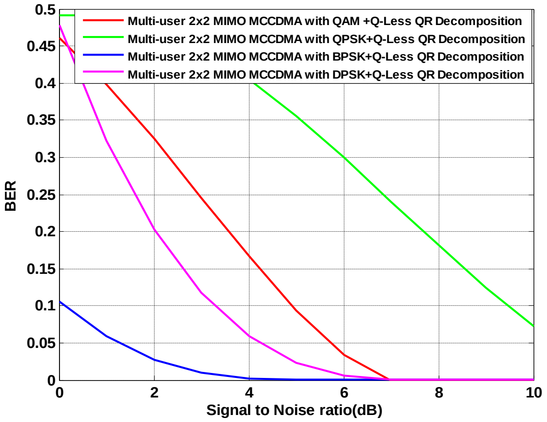

Figure 5. BER Performance for multi-user MIMO MCCDMA wireless communication system with implementation of Q-Less QR Decomposition based signal detection scheme under different digital modulations.

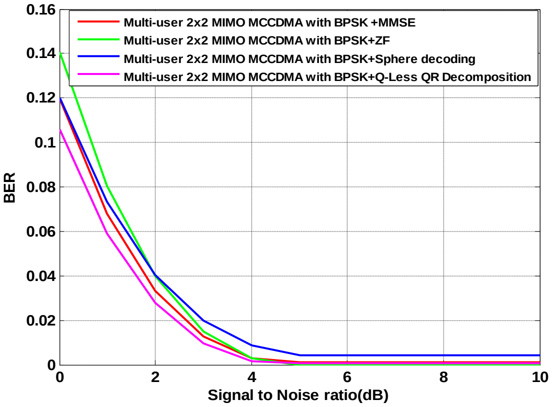

Figure 6. BER Performance of the multi-user MIMO MCCDMA wireless communication system under implementation of various signal detection scheme and BPSK digital modulation.

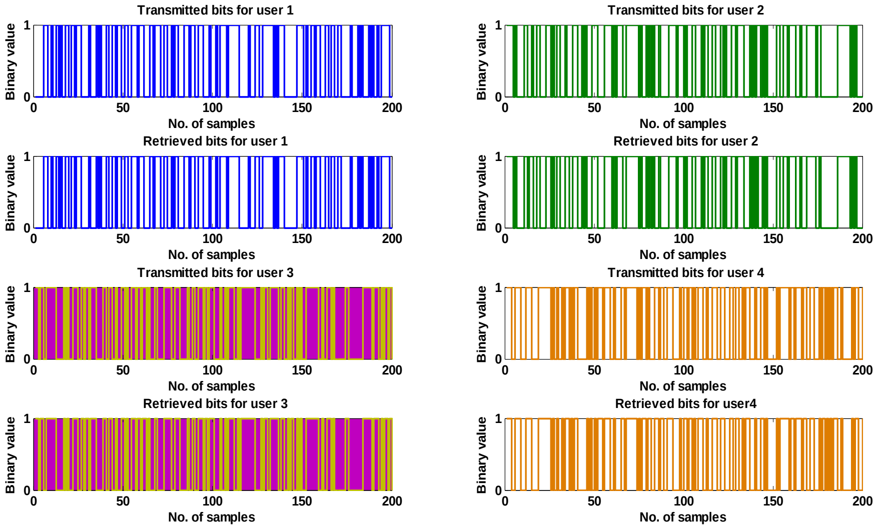

Figure 7. Transmitted and Retrieved bits for four users in a Multi-user MIMO MCCDMA Wireless communication system under implementation of Q-less QR decomposition based signal detection scheme under BPSK digital modulation.

3. Conclusions

In this paper, we have presented simulation results concerning the adaptation of various signals detection schemes in a multi-user MIMO MCCDMA wireless communication system. A range of system performance results highlights the impact of signal detection scheme on synthetically generated bit stream. In the context of system performance, it can be concluded that the implementation of BPSK digital modulation technique in Q-less QR Decomposition based signal detection technique provides satisfactory result for such a multi-user MIMO MCCDMA wireless communication system.

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