Performance Evaluation of a Multi Antenna MC-CDMA System on Color Image Transmission under Implementation of Various Signal Detection Techniques

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Abstract

In this paper, we made a comprehensive study to evaluate the performance of a multi antenna supported multi carrier Code Division Multiple Access (MC-CDMA) system on color image transmission. The 2-by-2 spatially multiplexed ½-rated Convolutinally encoded MC-CDMA system under investigation implements three linear signal detection techniques (Equalizers) such as Minimum Mean Square Error (MMSE), Zero Forcing (ZF) and Sphere Decoding (SD) under BPSK, DPSK, QPSK and QAM digital modulations. The simulation results elucidate that a significant improvement of system performance is achieved in BPSK modulation with MMSE based signal detection scheme under AWGN and Rayleigh fading channels. The results are also indicative of noticeable reduction of BER performance with increase in order of digital modulation and noise power as compared to signal power.

Keywords: *MC-CDMA, Convolutional Encoding, Linear signal detection technique, Bit Error Rate (BER), AWGN and Rayleigh fading channels*

1. Introduction

Multi-carrier code division multiple access (MC-CDMA) is an orthogonal frequency-division multiplexing (OFDM)-based CDMA wireless communication system mitigating the problem of inter symbol interference (ISI) with exploitation of frequency diversity [1, 2]. With higher demands in performance and data transfer rates in modern digital wireless communication systems, the multi antenna supported (MIMO) MC-CDMA systems under implementation of space-time coding techniques are capable of achieving high spectral efficiency and high link reliability over frequency selective wireless channels and improving significantly the capacity of wireless communication systems and performance [3]. The MC-CDMA is a hybrid transmission technique employing an amalgam of Code Division Multiple Access (CDMA) and Orthogonal Frequency Division Multiplexing (OFDM) and is expected to combine the benefits of pure CDMA and OFDM techniques. The 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. In CDMA systems, multi users share a same higher bandwidth than the modulating signal's bandwidth using different spreading codes. Due to implementation of noise-like spreading sequences, the Inter-Symbol Interference (ISI) is reduced significantly in frequency selective multi-path fading environments. 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) [4, 5].

2. Mathematical Model

In our presently considered spatially multiplexed Channel encoded MC-CDMA wireless communication system, Alamouti's G2 space time block coding scheme has been implemented with three signal detection schemes (MMSE, ZF and SD). A brief description is given below.

In Alamouti's G2 Space time block coding scheme, 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 s1 and from the second antenna by s2. During the next symbol period, the signal - s2* is transmitted from the first antenna and the s1* is transmitted from the second antenna where * is indicative of complex conjugate operation [6].

3. Signal Detection

We assume that the signal detection scheme will be implemented in a 2x2 spatially multiplexed MCCDMA system. Let H denote a channel matrix with it (j,i)th entry h_{ij} for the channel gain between the ith transmit antenna and the jth receive antenna, j=1,2 and i=1,2.. The spatially-multiplexed user data and the corresponding received signals are represented by $x=[x_1, x_2]^T$ and $y=[y_1,y_2]^T$ respectively, where x_i and y_i denote the transmit signal from ith transmitting antenna and the received signal at the jth receiving antenna respectively. Let n_j denote the white Gaussian noise with a variance of σ_n^2 at the jth receiving antenna and h_i denote the ith column vector of the channel matrix H. The received signal y for the system can be represented as

$$y = Hx + n = h_1 x_1 + h_2 x_2 + n \qquad (1)$$

where, $n = [n_1, n_2]^T$

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

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

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

$$W_{MMSE} = (H^H H + \sigma_n{}^2 I)^{-1} H^H \qquad (2)$$

where $(.)^H$ denotes the Hermitian transpose operation. The detected desired signal from the transmitting antenna is given by

$$\tilde{x}_{MMSE} = W_{MMSE}\, y \qquad (3)$$

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

$$W_{ZF} = (H^H H)^{-1} H^H \qquad (4)$$

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

$$\tilde{x}_{ZF} = W_{ZF} y \qquad (5)$$

The Sphere Decoding (SD) signal detection scheme is intended to find the transmitted signal vector with minimum ML metric. The 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 exists 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 it 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:

$$\begin{bmatrix} y_{1R} + jy_{1I} \\ y_{2R} + jy_{2I} \end{bmatrix} = \begin{bmatrix} h_{11R} + jh_{11I} & h_{12R} + jh_{12I} \\ h_{21R} + jh_{21I} & h_{22R} + jh_{22I} \end{bmatrix} \begin{bmatrix} x_{1R} + jx_{1I} \\ x_{2R} + jx_{2I} \end{bmatrix} + \begin{bmatrix} n_{1R} + jn_{1I} \\ n_{2R} + jn_{2I} \end{bmatrix} \qquad (6)$$

where h_{ij} = Re{h_{ij}}, h_{ij} = Im{h_{ij}}, n_i = Re{n_i}, and n_i = Im{n_i}. The real imaginary parts of Equation (6) can be respectively expressed as

$$\begin{bmatrix} y_{1R} \\ y_{2R} \end{bmatrix} = \begin{bmatrix} h_{11R} & h_{12R} \\ h_{21R} & h_{22R} \end{bmatrix} \begin{bmatrix} x_{1R} \\ x_{2R} \end{bmatrix} - \begin{bmatrix} h_{11I} & h_{12I} \\ h_{21I} & h_{22I} \end{bmatrix} \begin{bmatrix} x_{1I} \\ x_{2I} \end{bmatrix} + \begin{bmatrix} n_{1R} \\ n_{2R} \end{bmatrix} = \begin{bmatrix} h_{11R} & h_{12R} & -h_{11I} & -h_{12I} \\ h_{21R} & h_{22R} & -h_{21I} & -h_{22I} \end{bmatrix} \begin{bmatrix} x_{1R} \\ x_{2R} \\ x_{1I} \\ x_{2I} \end{bmatrix} + \begin{bmatrix} n_{1R} \\ n_{2R} \end{bmatrix} \qquad (7a)$$

and $$\begin{bmatrix} y_{1I} \\ y_{2I} \end{bmatrix} = \begin{bmatrix} h_{11I} & h_{12I} & h_{11R} & h_{12R} \\ h_{21I} & h_{22I} & h_{21R} & h_{22R} \end{bmatrix} \begin{bmatrix} x_{1R} \\ x_{2R} \\ x_{1I} \\ x_{2I} \end{bmatrix} + \begin{bmatrix} n_{1I} \\ n_{2I} \end{bmatrix} \qquad (7b)$$

The above two Equations (7a) and (7b) can be combined to yield the following expression:

$$\underbrace{\begin{bmatrix} y_{1R} \\ y_{2R} \\ y_{1I} \\ y_{2I} \end{bmatrix}}_{\bar{y}} = \underbrace{\begin{bmatrix} h_{11R} & h_{12R} & -h_{11I} & -h_{12I} \\ h_{21R} & h_{22R} & -h_{21I} & -h_{22I} \\ h_{11I} & h_{12I} & h_{11R} & h_{12R} \\ h_{21I} & h_{22I} & h_{21R} & h_{22R} \end{bmatrix}}_{\bar{H}} \underbrace{\begin{bmatrix} x_{1R} \\ x_{2R} \\ x_{1I} \\ x_{2I} \end{bmatrix}}_{\bar{x}} + \underbrace{\begin{bmatrix} n_{1R} \\ n_{2R} \\ n_{1I} \\ n_{2I} \end{bmatrix}}_{\bar{z}} \qquad (8)$$

For $\bar{y}$, $\overline{H}$, $\bar{x}$ and $\bar{z}$ defined in Equation (8), the SD method exploits the following relation:

$$\arg\min_{\bar{x}} \| \bar{y} - \bar{H}\bar{x} \|^2 = \arg\min_{\bar{x}} (\bar{x} - \hat{\bar{x}})^T \bar{H}^T \bar{H} (\bar{x} - \hat{\bar{x}}) \qquad (9)$$

The detected desired signal from the transmitting antenna can be obtained from Equation (8) using the following relation[7]

$$\bar{x} = (\bar{H}^H \bar{H})^{-1} \bar{H}^H \bar{y} \qquad (10)$$

4. Simulation Model

A simulated multi-user MC-CDMA communication system depicted in Figure-1 utilizes a ½-rated Convolutional coding scheme with two transmit and two receive antennas. In this simulated system, we have assumed that two users are transmitting their color image data simultaneously. Two uncompressed RGB images in JPEG format have been used as the input sources. The analog image data for each user is converted to 100×100 digital image components with R-G-B samples.

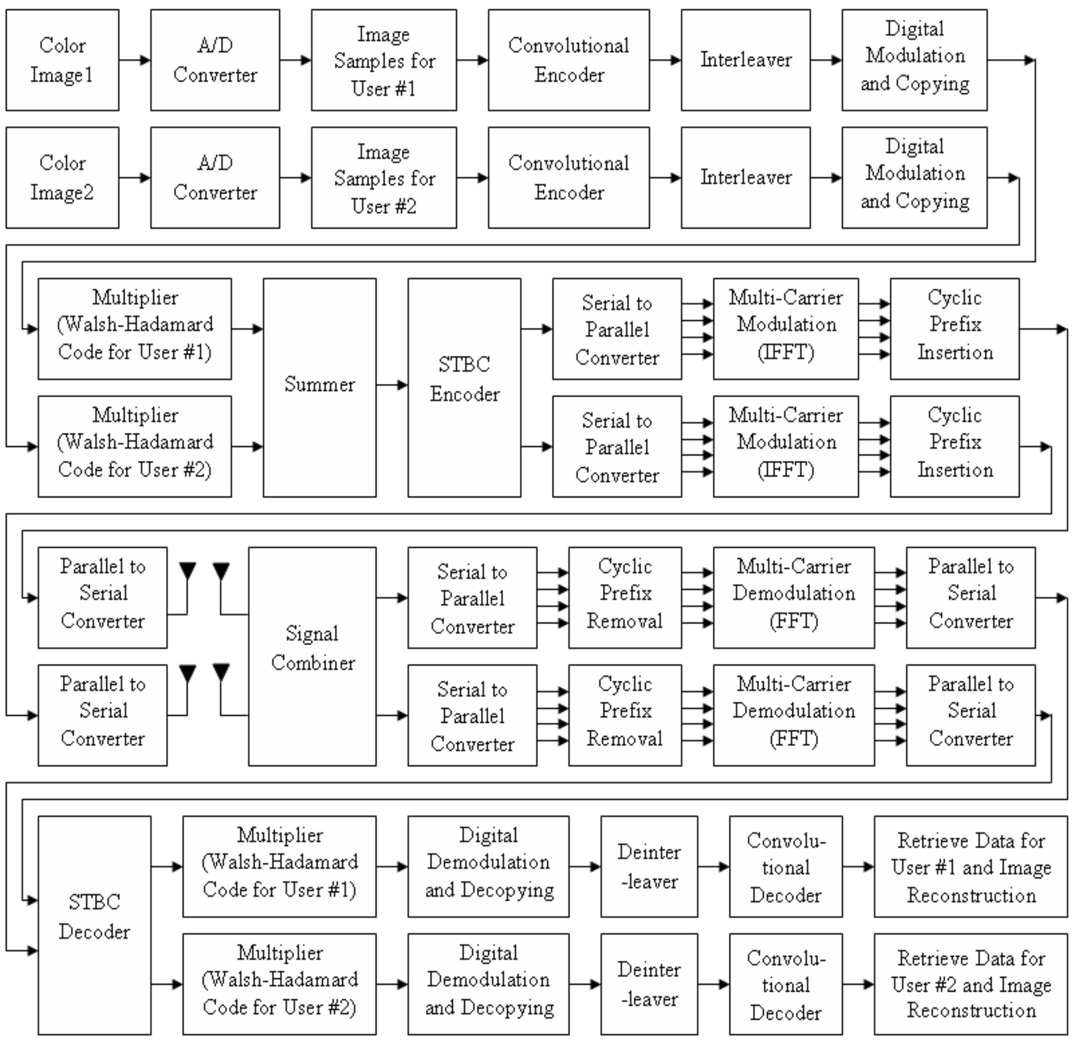

Figure 1. Block Diagram of a Convolutional Encoded Multi antenna Supported MC-CDMA System for Color Image Transmission

These samples are then serially multiplexed and channel encoded using a ½-rated Convolutional encoder. The encoded bit stream is then interleaved to minimize the burst error effect. The output of the interleaver is digitally modulated using different digital modulation schemes such as Binary Phase Shift Keying (**BPSK**), Differential Phase Shift Keying (**DPSK**), Quadrature Phase Shift Keying (**QPSK**) and Quadrature Amplitude Modulation (**QAM**). 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. The output of the Space-time block encoder is 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 modulators 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+ L_{cp}) are launched 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 two individual sections. In each of the two sections, the complex symbols are digitally demodulated, decopied, deinterleaved and convolutionally decoded to recover the transmitted data for image reconstruction.[8, 9].

5. Results and Discussion

We have conducted MATLAB based computer simulations to evaluate the BER performance of a 2x2 multi antenna supported Channel encoded MC-CDMA wireless communication system based on the parameters given in Table 1.

Table 1. Summary of the Simulated Model Parameters

Parameters	Values
Input data (Color image)	100×100 pixels
Channel encoding	½-rated Convolutional encoder
Symbol mapping	BPSK, DPSK, QPSK and QAM
Antenna configuration	2-by-2
Processing Gain	8
No. of OFDM sub-carriers	1024
CP length	103 symbols
Spreading Code	Walsh-Hadamard
Signal to noise ratio, SNR	0 to 10 dB

Channel	AWGN and Rayleigh fading
Detection techniques	Zero Forcing (ZF), Minimum Mean Square Error (MMSE) and Sphere Decoding (SD)

It is assumed that the channel state information (CSI) is available at the receiver and the fading process is approximately constant during period of signal transmitted from each of the two antennas. The graphical illustrations presented in Figure 2 through Figure 4 show a remarkable performance enhancement of the multi user multi antenna supported MC- CDMA system in BPSK digital modulation. The system shows worst performance in QPSK modulation under implementation of each of the three signal detection schemes. In Figure 2(a), the BER values are 0.0054, and 0.2792 for a typically assumed SNR value of 3dB in case of BPSK and QPSK digital modulations viz., the system performance is improved in BPSK by 17.135 dB as compared to QPSK for transmitted color image of user 1 in MMSE signal detection scheme. In Figure 2(b), the estimated BER are found to have values of 0.0063 and 0.2666 correspondingly in case of transmitted color image of user 2 viz., the system performance is improved in BPSK by 16.265 dB as compared to QPSK.

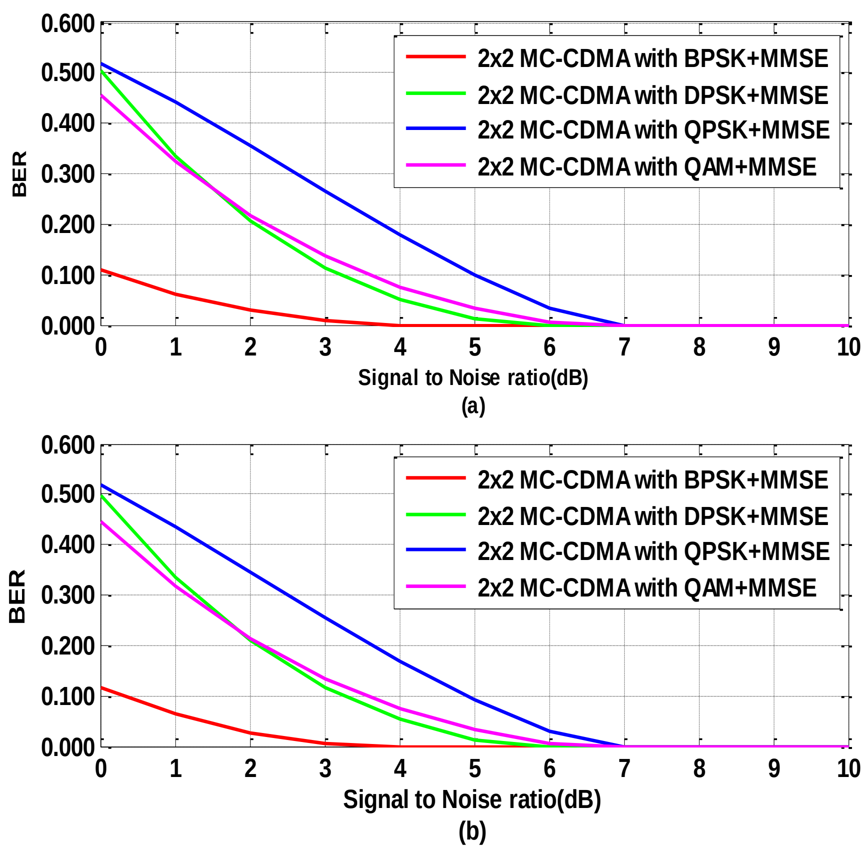

Figure 2. BER performance of a ½-rated Convolution encoded 2x2 MC-CDMA system using four modulation schemes with implementation of Minimum Mean Square Error (MMSE) signal detection technique, (a) for user #1 and (b) for user #2

In Figure 3(a), the BER values are 0.0078 and 0.2587 for a typically assumed SNR value of 3dB in case of BPSK and QPSK digital modulations viz., the system performance is improved in BPSK by 15.207 dB as compared to QPSK for transmitted color image of user 1 in ZF signal detection scheme. In Figure 3(b), the estimated BER are found to have values of 0.0085 and 0.2854 correspondingly in case of transmitted color image of user 2 viz., the system performance is improved in BPSK by 15.260 dB as compared to QPSK.

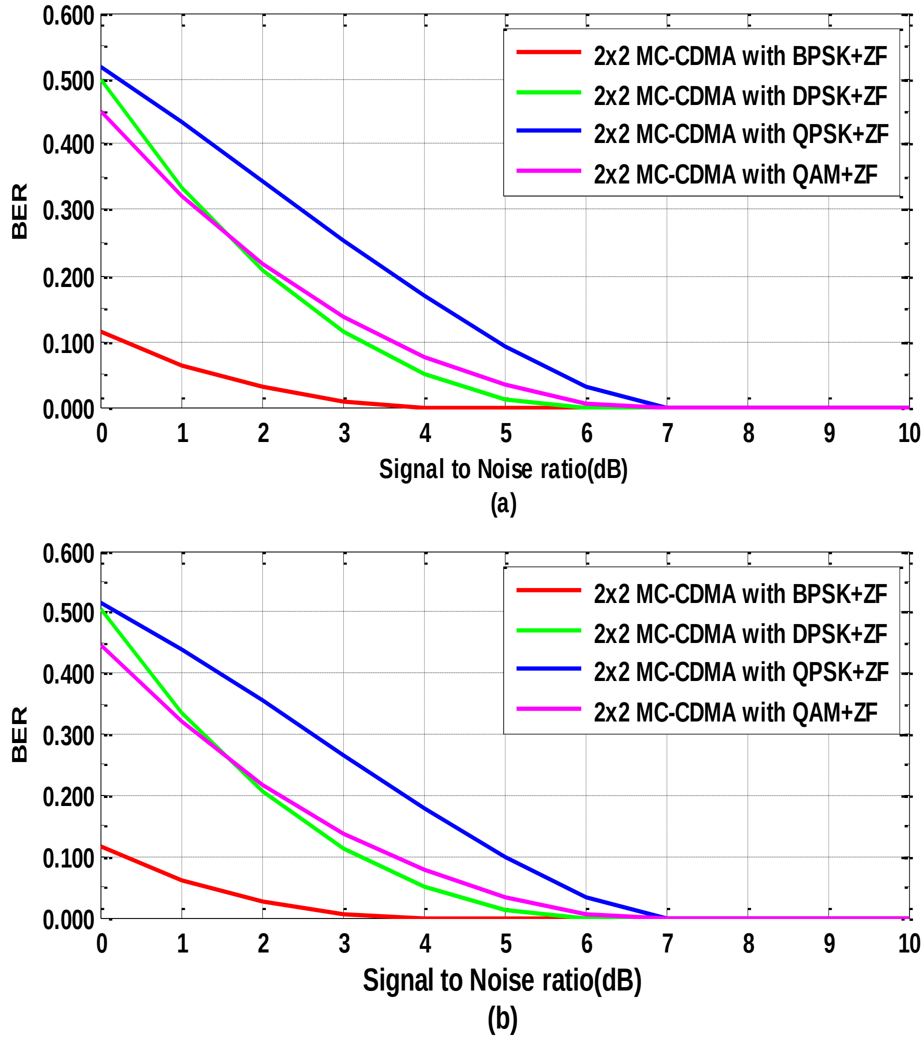

Figure 3. BER performance of a ½-rated Convolution encoded 2x2 MC-CDMA system using four modulation schemes with implementation of Zero Forcing (ZF) signal detection technique, (a) for user #1 and (b) for user #2

In Figure 4(a), the BER values are 0.0087 and 0.2880 for a typically assumed SNR value of 3dB in case of BPSK and QPSK digital modulations viz., the system performance is improved in BPSK by 15.198 dB as compared to QPSK for transmitted color image of user 1 in SD signal detection scheme. In Figure 4(b), the estimated BER are found to have values of

0.0068 and 0.2750 correspondingly in case of transmitted color image of user 2 viz., the system performance is improved in BPSK by 16.068 dB as compared to QPSK.

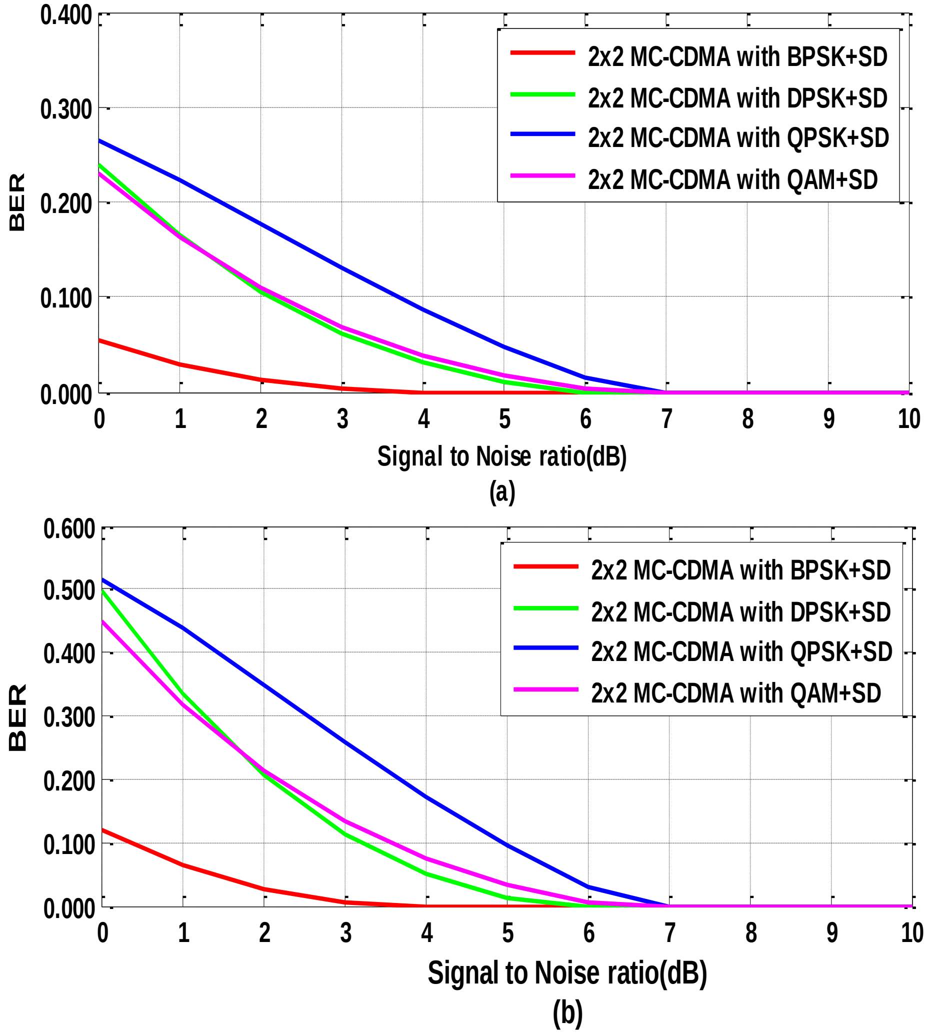

Figure 4. BER performance of a ½-rated Convolution encoded 2x2 MC-CDMA system using four modulation schemes with implementation of Sphere Decoding (SD) signal detection technique, (a) for user #1 and (b) for user #2

On critical observation of BER graphs presented in Figure 2 through Figure 4 and numerically estimated BER values, it has been acceptable that the simulated system outperforms in BPSK digital modulation under implementation of MMSE signal detection technique. However, the transmitted and retrieved color images for user 1 and user 2 at different SNR values are shown in Figure 5 and Figure 6 respectively. In both cases, quality of retrieved color image is improved with increase in SNR value.

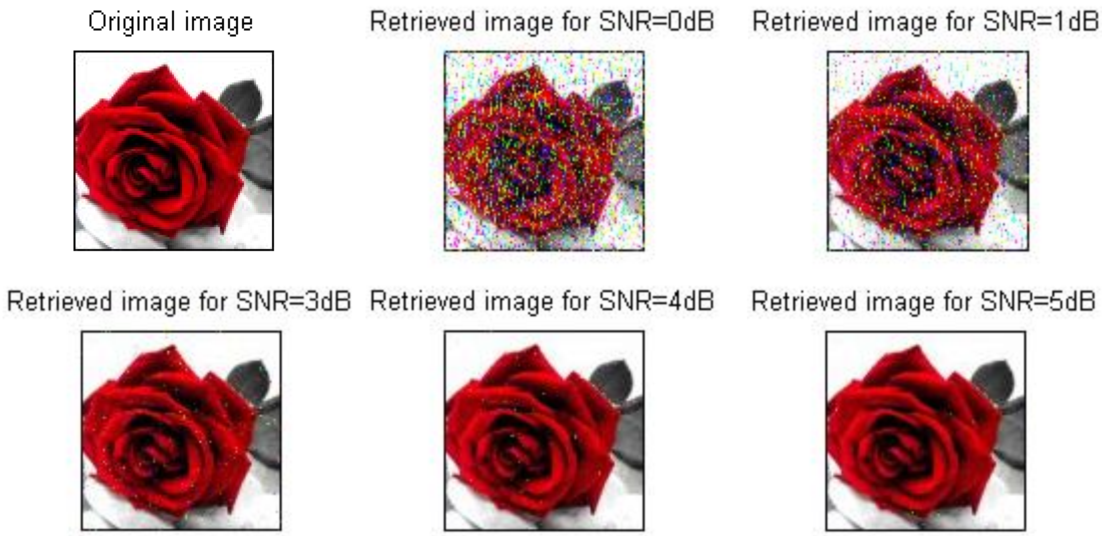

Figure 5. Transmitted and retrieved color images for user #1 under implementation of Minimum Mean Square Error (MMSE) signal detection technique in BPSK digital modulation at different Signal-to-Noise ratio (SNR)

Figure 6. Transmitted and retrieved color images for user #2 under implementation of Minimum Mean Square Error (MMSE) signal detection technique in BPSK digital modulation at different Signal-to-Noise ratio (SNR)

6. Conclusion

In this present study, we have observed the performance of a ½-rated Convolutional encoded multi-user and multi antenna supported MC-CDMA system on color image transmission with different digital modulations and signal detection techniques. A wide range of performance results highlights significantly the impact of different modulations and signal detection schemes. On the basis of the simulation results obtained in this present study, it can be concluded that the system shows an improved BER performance under BPSK digital modulation and MMSE detection technique in noisy and fading environment and the simulated system is very much effective in proper identification and retrieval of transmitted color image at significantly lower SNR value.

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