



International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS)

www.iasir.net

Impact of MGSTC BLAST spatial multiplexing scheme on performance assessment of MCCDMA wireless communication system

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Abstract: In this paper, an effort has been made to observe critically the Impact of MGSTC BLAST spatial multiplexing scheme on color image transmission in a MCCDMA wireless communication system. The simulated system incorporates various signal detection techniques such as MMSE, ZF, OSIC and MMSE-SIC under 4×4 antenna configuration. In perspective of data protection, $\frac{1}{2}$ -rated irregular LDPC and Repeat and Accumulate forward error correction(channel encoding) schemes have been used.. It is noticeable from MATLAB based simulative study that the system shows quite satisfactory performance in retrieving transmitted color image under scenario of hostile fading channel environment with implementation of MMSE-SIC signal detection, 16QAM digital modulation and Repeat and Accumulate channel coding scheme.

Keywords: MCCDMA, MMSE, ZF, OSIC, MMSE-SIC, LDPC, Repeat and Accumulate, Signal to noise ratio(SNR)

I. Introduction

The multi carrier CDMA(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 MC-CDMA is an attractive choice for high speed wireless communication as it mitigates the problem of intersymbol interference (ISI) with exploitation of frequency diversity. It supports multiple users with high speed data communications. The CDMA technique is widely used in current Third Generation (3G) wireless communication systems(W-CDMA-Wideband Code Division Multiple Access, UMTS-Universal Mobile Telecommunications etc) presenting a wide range higher data rate supported services such as voice/video/data (IP Television, video on demand, video conferencing, tele-medicine)[1,2]. The OFDM techniques are employed in the American National Standards Institute's (ANSI's) Asymmetric Digital Subscriber Line (ADSL), High-bit-rate Digital Subscriber Line (HDSL), and Very-high-speed Digital Subscriber Line (VDSL) standards as well as in the European Telecommunication Standard Institute's (ETSI's) VDSL applications. In wireless scenarios, OFDM has been 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). The MC-CDMA transmission technique has become increasingly popular in wireless communications due to its high spectral efficiency, robustness to frequency selective fading and flexibility to support integrated applications.[3,4]. In our present study, a MGSTC BLAST spatial multiplexing scheme has been used in MC-CDMA system with a view to observing its system performance on color image transmission.

II. Signal Processing and Detection Scheme

In our present study various signal processing and detection schemes have been used. A brief overview of these schemes is given below:

A. Repeat and Accumulate (RA)

In RA, a powerful modern error-correcting coding scheme, the extracted binary bits from the color image is rearranged into blocks with each block containing 2048 binary bits. The binary bits in each block is repeated 2 times and permuted by an interleaver of length 4096. The interleaved binary data block z is passed through a truncated rate-1 two-state convolutional encoder whose output x is the Repeat and Accumulate encoded binary data and is given by $x = zG$, where G is an 4096×4096 matrix with 1s on and above its main diagonal and 0s elsewhere[5]. The RA encoded blocked binary data are further processed to produce a 442368×1 single column vector data.

B. Low density parity-check matrix (LDPC)

In LDPC coding, $\frac{1}{2}$ -rated irregular LDPC code is used with a code length of 1024 bits. Its parity-check matrix $[H]$ is a sparse matrix with a dimension of 512×1024 and contains only three 1's in each column

and six 1's in each row. The parity-check matrix $[H]$ is formed from a concatenation of two matrices $[A]$ and $[P]$ ($[H]=[A][P]$), each has a dimension of 512×512). The columns of the parity-check matrix $[H]$ is rearranged to produce a new parity-check matrix $[newH]$. With rearranged matrix elements, the matrix $[A]$ becomes non-singular and it is further processed to undergo LU decomposition. The parity bits sequence $[p]$ is considered to have been produced from a block based input binary data sequence $[u]=[u_1u_2u_3u_4.....u_{512}]^T$ and three matrices $[P]$ (of $[newH]$), $[L]$ and $[U]$ using the following Matlab notation :

$p = \text{mod}(U(L/z), 2);$ where, $z = \text{mod}(P*u, 2);$

The LDPC encoded 1024×1 sized block based binary data sequence $[c]$ is formulated from concatenation of parity check bit p and information bit u as :

$[c]=[p;u]$

The first 512 bits of the codeword matrix $[c]$ are the parity bits and the last 512 bits are the information bits. In iterative Log Domain Sum-Product LDPC decoding Algorithm, the transmitted bits are retrieved [6,7].

C. Multi-group space-time coding (MGSTC)

Spatial multiplexing is generally referred to transmitting multiple independent data streams over multipath channels. The multi-group space-time coding (MGSTC) scheme achieves both spatial multiplexing and spatial diversity simultaneously. In such scheme, the digitally modulated symbols are rearranged into four groups with each group consisting of sixteen symbols at a time. The total number of information bits processed in each group under each of the four space time encoder are sixty four as the 16th order digital modulations (16-QAM and 16-PSK) have been used. [8]

D. Minimum mean square error (MMSE)

We assume that the color image is preprocessed through various schemes prior to Multi-group space-time encoding and transmitted through a MIMO fading channel. The received signal Y in terms of channel matrix H , transmitted signal X and additive white Gaussian noise (AWGN) N with a variance of σ_n^2 can be written as

$$Y=HX+N \quad (1)$$

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

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

Where $(.)^H$ denotes the Hermitian transpose operation and The detected desired signal $\tilde{X}_{MMSE}$ from the transmitting antenna is given by

$$\tilde{X}_{MMSE} = W_{MMSE} Y \quad (3)$$

E. Zero-Forcing (ZF)

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

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

and the detected desired signal $\tilde{X}_{ZF}$ from the transmitting antenna is given by [9]

$$\tilde{X}_{ZF} = W_{ZF} Y \quad (5)$$

F. Minimum mean square error successive interference cancellation (MMSE-SIC)

In Minimum mean square error successive interference cancellation (MMSE-SIC) scheme,

The extended channel matrix $\bar{H}$ and the extended received signal $\bar{Y}$ in terms of identity and null matrices are given by

$$\bar{H} = \begin{bmatrix} H \\ (\sqrt{\sigma_n^2}) I \end{bmatrix} \quad (6)$$

$$\bar{Y} = \begin{bmatrix} Y \\ 0 \end{bmatrix} \quad (7)$$

On QR decomposition of $\bar{H}$, an orthogonal matrix $\bar{Q}$ and an upper triangular matrix $\bar{R}$ are produced.

Equation (7) is multiplied with $\bar{Q}^T$ to provide a modified form of received signal $\bar{\bar{Y}}$ with neglected noise component[10]

$$\bar{\bar{Y}} = \bar{Q}^T \bar{Y} = \bar{Q}^T \bar{H} X = \bar{\bar{R}} X \quad (8)$$

Considering a single time slot, the transmitted four signals $\bar{\bar{X}}_1, \bar{\bar{X}}_2, \bar{\bar{X}}_3$ and $\bar{\bar{X}}_4$ in terms of four received signals $\bar{\bar{Y}}_1, \bar{\bar{Y}}_2, \bar{\bar{Y}}_3$ and $\bar{\bar{Y}}_4$ (First through Fourth rows of $\bar{\bar{Y}}$ and neglecting other row data) and the components of matrix $\bar{\bar{R}}$ in first through fourth row) can be obtained from a matrix equation as:

$$\bar{\bar{Y}}[:,1] = \begin{bmatrix} \bar{\bar{Y}}_1 \\ \bar{\bar{Y}}_2 \\ \bar{\bar{Y}}_3 \\ \bar{\bar{Y}}_4 \\ \bar{\bar{Y}}_5 \\ \bar{\bar{Y}}_6 \\ \bar{\bar{Y}}_7 \\ \bar{\bar{Y}}_8 \end{bmatrix} = \begin{bmatrix} \bar{\bar{R}}_{1,1} & \bar{\bar{R}}_{1,2} & \bar{\bar{R}}_{1,3} & \bar{\bar{R}}_{1,4} \\ 0 & \bar{\bar{R}}_{2,2} & \bar{\bar{R}}_{2,3} & \bar{\bar{R}}_{2,4} \\ 0 & 0 & \bar{\bar{R}}_{3,3} & \bar{\bar{R}}_{3,4} \\ 0 & 0 & 0 & \bar{\bar{R}}_{4,4} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \bar{\bar{X}}_1 \\ \bar{\bar{X}}_2 \\ \bar{\bar{X}}_3 \\ \bar{\bar{X}}_4 \end{bmatrix} \quad (9)$$

G. Ordered successive interference cancellation (OSIC)

In Ordered successive interference cancellation (OSIC) signal detection scheme, its implementation is performed in four steps. In first step, the first detected signal/data stream $\tilde{\bar{X}}_{\text{OSIC}-1}$ and modified form of received signal $\tilde{\bar{Y}}_{\text{OSIC}-1}$ can be written as:

$$\begin{aligned} \tilde{\bar{X}}_{\text{OSIC}-1} &= \mathbf{W}_{(\text{MMSE}(1,:))} \mathbf{Y} \\ \tilde{\bar{Y}}_{\text{OSIC}-1} &= \mathbf{Y} - \mathbf{H}_{(:,1)} \tilde{\bar{X}}_{\text{OSIC}-1} \end{aligned} \quad (10)$$

In second step, the second detected signal/data stream $\tilde{\bar{X}}_{\text{OSIC}-2}$ and modified form of received signal $\tilde{\bar{Y}}_{\text{OSIC}-2}$ can be written as:

$$\begin{aligned} \tilde{\bar{X}}_{\text{OSIC}-2} &= \mathbf{W}_{(\text{MMSE}(2,:))} \tilde{\bar{Y}}_{\text{OSIC}-1} \\ \tilde{\bar{Y}}_{\text{OSIC}-2} &= \tilde{\bar{Y}}_{\text{OSIC}-1} - \mathbf{H}_{(:,2)} \tilde{\bar{X}}_{\text{OSIC}-2} \end{aligned} \quad (11)$$

In third step, the third detected signal/data stream $\tilde{\bar{X}}_{\text{OSIC}-3}$ and modified form of received signal $\tilde{\bar{Y}}_{\text{OSIC}-3}$ can be written as:

$$\begin{aligned} \tilde{\bar{X}}_{\text{OSIC}-3} &= \mathbf{W}_{(\text{MMSE}(3,:))} \tilde{\bar{Y}}_{\text{OSIC}-2} \\ \tilde{\bar{Y}}_{\text{OSIC}-3} &= \tilde{\bar{Y}}_{\text{OSIC}-2} - \mathbf{H}_{(:,3)} \tilde{\bar{X}}_{\text{OSIC}-3} \end{aligned} \quad (12)$$

In fourth step, the fourth detected signal/data stream $\tilde{\mathbf{X}}_{\text{OSIC-4}}$ and modified form of received signal $\tilde{\mathbf{Y}}_{\text{OSIC-4}}$ can be written as:

$$\begin{cases} \tilde{\mathbf{X}}_{\text{OSIC-4}} = \mathbf{W}_{(\text{MMSE}(4,:))} \tilde{\mathbf{Y}}_{\text{OSIC-3}} \\ \tilde{\mathbf{Y}}_{\text{OSIC-4}} = \tilde{\mathbf{Y}}_{\text{OSIC-3}} - \mathbf{H}_{(:,4)} \tilde{\mathbf{X}}_{\text{OSIC-4}} \end{cases} \quad (13)$$

where, $\mathbf{W}_{(\text{MMSE}(1,:))}$, $\mathbf{W}_{(\text{MMSE}(2,:))}$, $\mathbf{W}_{(\text{MMSE}(3,:))}$ and $\mathbf{W}_{(\text{MMSE}(4,:))}$ are the first, second, third and fourth rows of MMSE weight matrix and $\mathbf{H}_{(:,1)}$, $\mathbf{H}_{(:,2)}$, $\mathbf{H}_{(:,3)}$, and $\mathbf{H}_{(:,4)}$ are the first, second, third and fourth columns of the channel matrix respectively. The detected desired signal $\tilde{\mathbf{X}}_{\text{OSIC}} \in \mathbb{C}^{4 \times 4562325}$ from the transmitting antenna is given by [11,9]

$$\tilde{\mathbf{X}}_{\text{OSIC}} = \begin{bmatrix} \tilde{\mathbf{X}}_{\text{OSIC-1}} \\ \tilde{\mathbf{X}}_{\text{OSIC-2}} \\ \tilde{\mathbf{X}}_{\text{OSIC-3}} \\ \tilde{\mathbf{X}}_{\text{OSIC-4}} \end{bmatrix} \quad (14)$$

III. System Description

A RGB color image with 96 pixels (width) × 96 pixels (height) is processed in a MCCMA system depicted in Figure 1. The color image is converted into their respective three Red, Green and Blue components with each component is of 96 pixels × 96 pixels in size. The pixel integer values [0-255] are converted into 8 bits binary form and channel coded and interleaved and digitally modulated using 16QAM, 16PSK and 16-DPSK. The modulated complex symbols are copied and multiplied with Walsh-Hadamard (WH) orthogonal codes. The orthogonally encoded signals are processed in MGSTC BLAST aided Spatial multiplexing (SM) Encoding section to produce four independent data streams. Each of four data streams are serial to parallel converted, OFDM modulated, cyclically prefixed and subsequently parallel to serially converted and transmitted. In receiving section, the transmitted signals are detected and processed for serial to parallel conversion, cyclic prefix removal, OFDM demodulation, parallel to serial conversion and decoded in Spatial multiplexing (SM) Decoding section to produce data in single channel. The retrieved data are multiplied with Walsh-Hadamard (WH) orthogonal codes and decoded, digitally demodulated, deinterleaved, channel decoded, binary to pixel integer converted and eventually reconstructed for transmitted color image retrieval. [12,13]

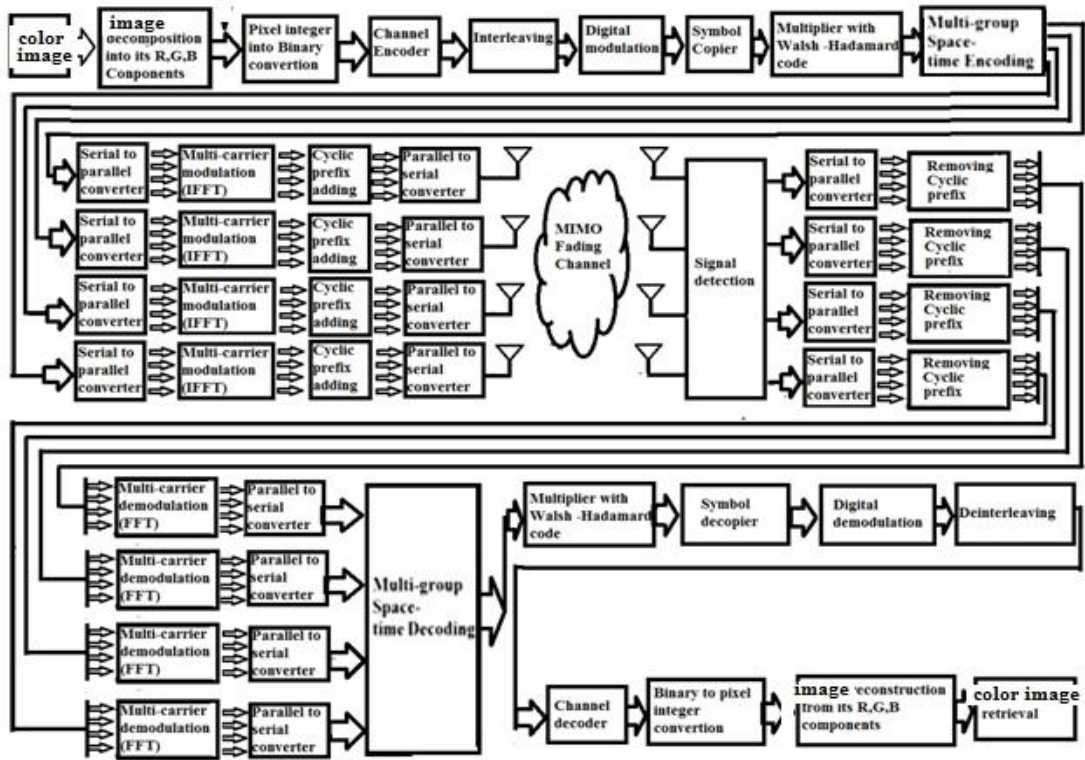


Figure 1: Block diagram of simulated MGSTC BLAST spatial multiplexing scheme aided MCCMA wireless communication system

IV. Results and Discussion

In this section, we have presented a series of simulation results to illustrate the significant impact of system performance in terms of BER in a multi-group space time encoded BLAST SM MCCDMA system with simulation parameters tabulated in Table 1.

Table 1: Summary of the Simulated Model Parameters

Data type	Color image (96x96x3 pixels)
Antenna configuration	4-by-4
Spatial multiplexing	Multi-group space time(MGST)
Channel Coding	Repeat and Accumulate Code and LDPC
Orthogonal spreading code	Walsh-Hadamard
Processing gain of Walsh-Hadamard code	8
Antenna configuration	4 × 4
Data Modulation	16-PSK and 16-QAM
IFFT/FFT size	1024
Signal detection Scheme	MMSE-SIC, OSIC, MMSE and ZF
Channel	AWGN and Rayleigh fading
Signal to noise ratio, SNR	0 to 5 dB

On critical observation of graphical illustrations presented in Figure 2 through Figure 5, it is quite evident that the MGSTC BLAST SM aided MCCDMA system shows comparatively satisfactory performance with 16QAM digital modulation and Repeat and Accumulate channel coding over a lower part of SNR values where the fading channel may be treated as hostile. In Figure 2 of MMSE implemented system, the estimated BER values for 16PSK digital modulation and LDPC channel coding as compared to 16QAM digital modulation and Repeat and Accumulate channel coding are 0.1849 and 0.0275 for a typically assumed SNR value of 0.5 dB which indicates a system performance improvement of 8.28dB. In case of identical signal and noise power at 0dB, the estimated BER value under utilization of MMSE, 16QAM and Repeat and accumulate channel coding is merely 3.46%. In Figure 3 for OSIC implemented system, the performance is very much well defined and discriminated. The system shows satisfactory performance in 16QAM and Repeat and accumulate channel coding over a low SNR value region, and worst performance in 16PSK and LDPC channel coding. Under such cases, the estimated BER values at 0.5 dB SNR values are found to be of 0.0214 and 0.1853 which makes a confirmation of 9.37 dB system performance improvement. At 5% BER, a SNR improvement of 2.7 dB is found in 16QAM and LDPC as compared to 16PSK and LDPC. In Figure 4 for MMSE-SIC implemented system, it shows satisfactory performance in 16QAM and Repeat and accumulates channel coding and worst performance in 16PSK and LDPC channel coding. In such cases, the estimated BER values are 0.0206 and 0.1874 for a typically assumed SNR value of 0.5dB which indicates a system performance improvement of 9.59dB.

Figure 5 for ZF implemented system, it shows satisfactory performance in 16QAM and Repeat and accumulate channel coding and worst performance in 16PSK and LDPC channel coding., the estimated BER values are 0.0211 and 0.1839 for a typically assumed SNR value of 0.5dB which indicates a system performance improvement of 9.40dB. The system performance is found to be almost identical for a wide range of SNR values in case of 16QAM with LDPC and of 16QAM with Repeat and accumulate channel coding. On critical observation on all simulated results, it has been ratified that the simulated system shows satisfactory performance in MMSE-SIC signal detection and 16QAM digital modulation. In Figure 6, the transmitted and retrieved color images have been presented with MMSE-SIC signal detection, 16QAM digital modulation and Repeat and Accumulate channel coding.

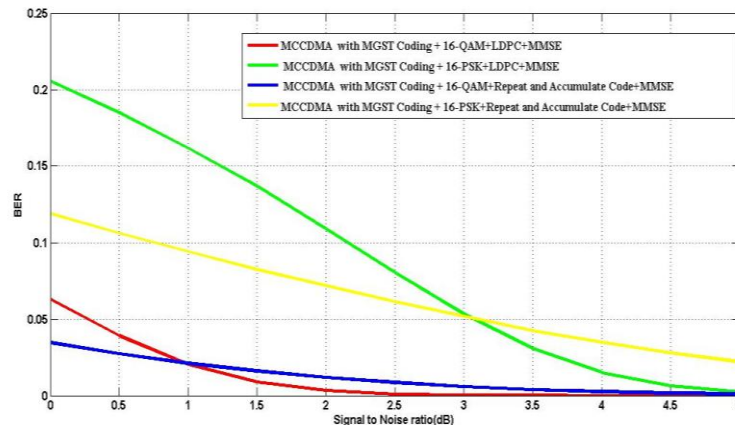


Figure 2: BER performance comparison of MGSTC BLAST spatial multiplexing scheme aided MCCDMA wireless communication system under various digital modulations and MMSE signal detection scheme

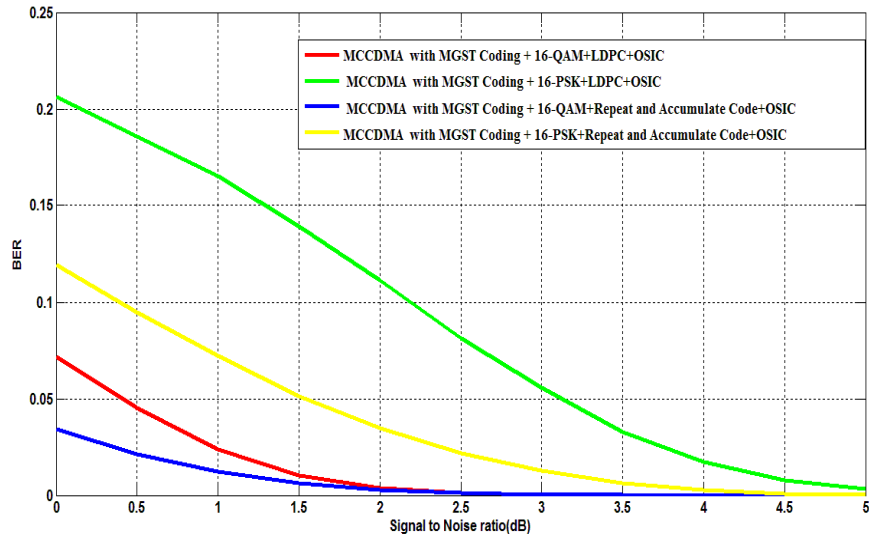


Figure 3: BER performance comparison of MGSTC BLAST spatial multiplexing scheme aided MCCDMA wireless communication system under various digital modulations and OSIC signal detection scheme

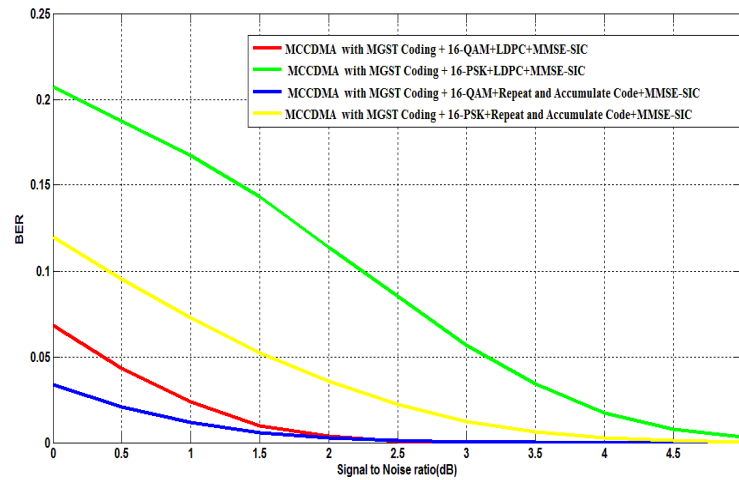


Figure 4: BER performance comparison of MGSTC BLAST spatial multiplexing scheme aided MCCDMA wireless communication system under various digital modulations and MMSE-SIC signal detection scheme

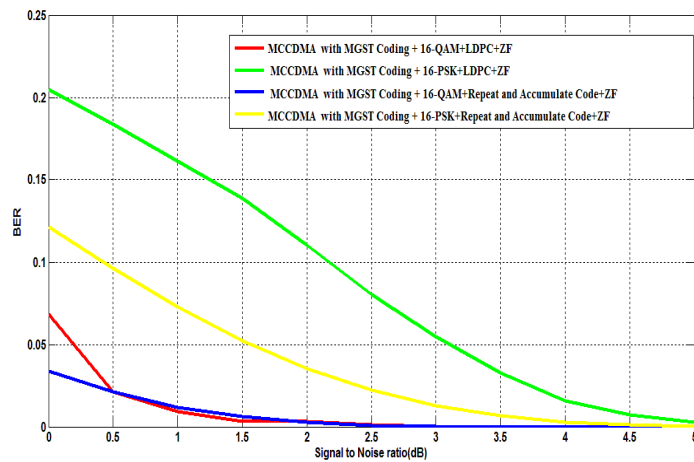


Figure 5: BER performance comparison of MGSTC BLAST spatial multiplexing scheme aided MCCDMA wireless communication system under various digital modulations and ZF signal detection scheme

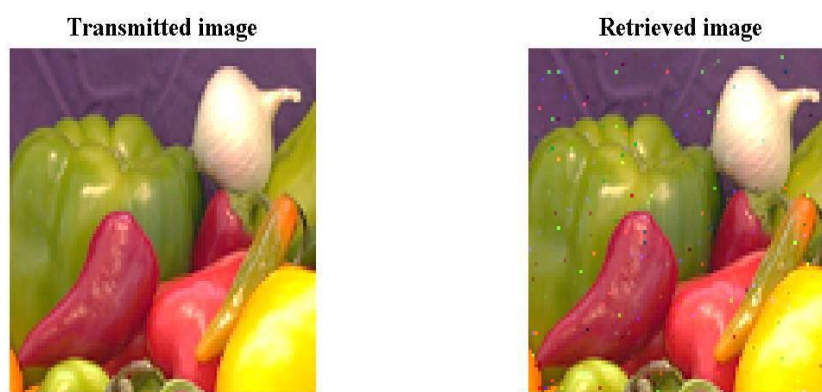


Figure 6: Performance indicator of MGSTC BLAST spatial multiplexing scheme aided MCCDMA wireless communication system under implementation of MMSE-SIC signal detection, 16-QAM digital modulation for a typical image at SNR value of 3dB

V. Conclusions

In this paper, the performance of MGSTC BLAST spatial multiplexing scheme aided MCCDMA wireless communication system has been investigated on color image transmission using various signal detection and FEC channel encoded schemes. The results show that the implementation of MMSE-SIC signal detection scheme with Repeat and Accumulate channel coding and 16QAM digital modulation ratifies the robustness of system performance in retrieving color image transmitted over Gaussian noise contaminated and Rayleigh fading channels. As MC CDMA radio interface technology exploits the advantages of both OFDM and CDMA, a great emphasis may be given on utilization of such technology in future generation wireless communication system.

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