



Quality Assessment of Encrypted Color Image in a D-BLAST aided LDPC encoded SC-FDMA Wireless Communication System

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Abstract: In this paper, we made a comprehensive study to evaluate the performance of LDPC encoded SC-FDMA Wireless Communication System on secure color image signal transmission. The 4-by-4 multi antenna supported SC-FDMA system incorporates various signal detection techniques such as Minimum mean square error (MMSE), Zero-Forcing (ZF), Zero-Forcing successive interference cancellation (ZF-SIC) Minimum mean square error successive interference cancellation (MMSE-SIC) and digital modulation schemes such as QPSK, QAM and DQPSK. It is observable from MATLAB based simulations that the system shows quite satisfactory and robust performance under scenario of ZF-SIC signal detection and QAM digital modulation schemes.

Keywords: SC-FDMA, LDPC, Signal detection scheme, SNR, D-BLAST

I. Introduction

Over the last two decades, a significant expansion in mobile and cellular technologies is observable to meet up the increasing demand for high data rate transmissions. Single-carrier frequency division multiple access (SC-FDMA), a modified form of orthogonal frequency division multiple access (OFDMA), has been adopted as the uplink physical layer radio access technique for the 3GPP Long Term Evolution (LTE) and 4G LTE-Advanced. The SC-FDMA system has attracted much attention due to its low PAPR with exploitation of advantage of the OFDMA system in combination with DFT spreading prior to the OFDMA modulation stage. The main advantages of the SC-FDMA system are that the envelope fluctuations are less pronounced and the power efficiency is higher than that of the OFDMA system. The wireless communication systems equipped with multiple transmitting and receiving antennas in perspective of SC-FDMA Implementation and cooperative systems is a very promising way to achieve large spectrum efficiency and capacity of mobile communication systems [1],[2].

The use of multiple input multiple output (MIMO) technique with utilization of multiple transmit and receive antennas are adopted in various Commercial wireless standards such as IEEE 802.11n (WiFi), IEEE 802.16e (WiMAX), HSPA+ (Enhanced HSPA), LTE (3.9G), LTE-Advanced (4G) and 802.11ac (Enhanced 802.11n). Such standards incorporate different types of multi-antenna techniques such as Alamouti space-time coding for transmit diversity, Eigen beam forming spatial multiplexing, BLAST spatial multiplexing architectures, Conventional beam and null forming and Conventional receive diversity. Under BLAST spatial multiplexing (SM) architectures, three Bell Laboratory layered space-time (BLAST) SM techniques have been known as: Vertical BLAST (V-BLAST), Horizontal BLAST (H-BLAST) and Diagonal BLAST (D-BLAST) [3],[4]. The present study investigates the performance of D-BLAST architecture with 4 x 4 antenna configuration for a LDPC encoded SC-FDMA wireless communication system on secure color image transmission.

II. Review of Signal Processing Techniques

We assumed that the color image is preprocessed in channel coding, interleaving, digital modulation, time domain to frequency domain and frequency domain to time domain signaling, spatial multiplexing (SM) encoding prior to transmission through a MIMO fading channel. The received signal $\mathbf{Y} \in \mathbb{C}^{4 \times 243324}$ in terms of channel matrix $\mathbf{H} \in \mathbb{C}^{4 \times 4}$, transmitted signal $\mathbf{X} \in \mathbb{C}^{4 \times 60831}$ and additive white Gaussian noise (AWGN) $\mathbf{N} \in \mathbb{C}^{4 \times 243324}$ with a variance of σ_n^2 can be written as

$$\mathbf{Y} = \mathbf{H}\mathbf{X} + \mathbf{N} \quad (1)$$

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

$$\mathbf{W}_{\text{MMSE}} = (\mathbf{H}^H \mathbf{H} + \sigma_n^2 \mathbf{I})^{-1} \mathbf{H}^H \quad (2)$$

Where $(.)^H$ denotes the Hermitian transpose operation and the detected desired signal $\tilde{\mathbf{X}}_{\text{MMSE}} \in \mathbb{C}^{4 \times 60831}$ from the transmitting antenna is given by

$$\tilde{\mathbf{X}}_{\text{MMSE}} = \mathbf{W}_{\text{MMSE}} \mathbf{Y} \quad (3)$$

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

$$\mathbf{W}_{\text{ZF}} = (\mathbf{H}^H \mathbf{H})^{-1} \mathbf{H}^H \quad (4)$$

and the detected desired signal $\tilde{\mathbf{X}}_{\text{ZF}} \in \mathbb{C}^{4 \times 60831}$ from the transmitting antenna is given by

$$\tilde{\mathbf{X}}_{\text{ZF}} = \mathbf{W}_{\text{ZF}} \mathbf{Y} \quad (5)$$

In Zero-Forcing successive interference cancellation (ZF-SIC) signal detection scheme, the channel matrix $\mathbf{H}$ is decomposed into a 4×4 orthogonal matrix $\mathbf{Q}$ and a 4×4 upper triangular matrix $\mathbf{R}$ and Equation (1) is multiplied with $\mathbf{Q}^T$ to provide a modified form of received signal $\bar{\mathbf{Y}} \in \mathbb{C}^{4 \times 243324}$ as:

$$\bar{\mathbf{Y}} = \mathbf{Q}^T \mathbf{Y} = \mathbf{Q}^T \mathbf{H} \mathbf{X} + \mathbf{Q}^T \mathbf{N} = \mathbf{R} \mathbf{X} + \mathbf{Q}^T \mathbf{N} = \mathbf{R} \mathbf{X} + \mathbf{N} \quad (6)$$

In Equation (6), $\mathbf{Q}^T \mathbf{N}$ is denoted by $\mathbf{N}$ as the statistical properties of both component are identical. Neglecting noise component and considering a single time slot, the transmitted four signals $\tilde{\mathbf{X}}_1, \tilde{\mathbf{X}}_2, \tilde{\mathbf{X}}_3$ and $\tilde{\mathbf{X}}_4$ in terms of four received signals $\bar{\mathbf{Y}}_1, \bar{\mathbf{Y}}_2, \bar{\mathbf{Y}}_3$ and $\bar{\mathbf{Y}}_4$ and the components of matrix $\mathbf{R}$ are estimated from solving the following matrix equation

$$\bar{\mathbf{Y}}[:,1] = \begin{bmatrix} \bar{\mathbf{Y}}_1 \\ \bar{\mathbf{Y}}_2 \\ \bar{\mathbf{Y}}_3 \\ \bar{\mathbf{Y}}_4 \end{bmatrix} = \begin{bmatrix} \mathbf{R}_{1,1} & \mathbf{R}_{1,2} & \mathbf{R}_{1,3} & \mathbf{R}_{1,4} \\ 0 & \mathbf{R}_{2,2} & \mathbf{R}_{2,3} & \mathbf{R}_{2,4} \\ 0 & 0 & \mathbf{R}_{3,3} & \mathbf{R}_{3,4} \\ 0 & 0 & 0 & \mathbf{R}_{4,4} \end{bmatrix} \begin{bmatrix} \tilde{\mathbf{X}}_1 \\ \tilde{\mathbf{X}}_2 \\ \tilde{\mathbf{X}}_3 \\ \tilde{\mathbf{X}}_4 \end{bmatrix} \quad (7)$$

$$\tilde{\mathbf{X}}_4 = \frac{\bar{\mathbf{Y}}_4}{\mathbf{R}_{4,4}}, \quad \tilde{\mathbf{X}}_3 = \frac{(\bar{\mathbf{Y}}_3 - \mathbf{R}_{3,4} \tilde{\mathbf{X}}_4)}{\mathbf{R}_{3,3}}, \quad \tilde{\mathbf{X}}_2 = \frac{(\bar{\mathbf{Y}}_2 - \mathbf{R}_{2,3} \tilde{\mathbf{X}}_3 - \mathbf{R}_{2,4} \tilde{\mathbf{X}}_4)}{\mathbf{R}_{2,2}} \quad \text{and} \quad (8)$$

$$\tilde{\mathbf{X}}_1 = \frac{(\bar{\mathbf{Y}}_1 - \mathbf{R}_{1,2} \tilde{\mathbf{X}}_2 - \mathbf{R}_{1,3} \tilde{\mathbf{X}}_3 - \mathbf{R}_{1,4} \tilde{\mathbf{X}}_4)}{\mathbf{R}_{1,1}}$$

In Minimum mean square error successive interference cancellation (MMSE-SIC) scheme, the extended 8×4 channel matrix $\hat{\mathbf{H}}$ and the extended 8×243324 received signal $\hat{\mathbf{Y}}$ in terms of 4×4 identity and 4×243324 null matrices are given by

$$\hat{\mathbf{H}} = \begin{bmatrix} \mathbf{H} \\ (\sqrt{\sigma_n^2}) \mathbf{I}_{4 \times 4} \end{bmatrix} \quad (9)$$

$$\hat{\mathbf{Y}} = \begin{bmatrix} \mathbf{Y} \\ \mathbf{0}_{4 \times 243324} \end{bmatrix} \quad (10)$$

on QR decomposition of $\hat{\mathbf{H}}$, a 8×8 orthogonal matrix $\hat{\mathbf{Q}}$ and a 8×4 upper triangular matrix $\hat{\mathbf{R}}$ are produced. Equation (14) is multiplied with $\hat{\mathbf{Q}}^T$ to provide a modified form of received signal $\hat{\hat{\mathbf{Y}}} \in \mathbb{C}^{8 \times 243324}$ with neglected noise component

$$\hat{\hat{\mathbf{Y}}} = \hat{\mathbf{Q}}^T \hat{\mathbf{Y}} = \hat{\mathbf{Q}}^T \hat{\mathbf{H}} \mathbf{X} = \hat{\mathbf{R}} \mathbf{X} \quad (11)$$

Considering a single time slot, the transmitted four signals $\hat{\hat{\mathbf{X}}}_1, \hat{\hat{\mathbf{X}}}_2, \hat{\hat{\mathbf{X}}}_3$ and $\hat{\hat{\mathbf{X}}}_4$ in terms of four received

signals $\hat{\hat{\mathbf{Y}}}_1, \hat{\hat{\mathbf{Y}}}_2, \hat{\hat{\mathbf{Y}}}_3$ and $\hat{\hat{\mathbf{Y}}}_4$ (First through Fourth rows of $\hat{\hat{\mathbf{Y}}}$ and neglecting other

row data) and the components of matrix $\hat{\mathbf{R}}$ in first through fourth row) can be obtained from a matrix equation as:

$$\hat{\mathbf{Y}}[:,1] = \begin{bmatrix} \hat{\mathbf{Y}}_1 \\ \hat{\mathbf{Y}}_2 \\ \hat{\mathbf{Y}}_3 \\ \hat{\mathbf{Y}}_4 \\ \hat{\mathbf{Y}}_5 \\ \hat{\mathbf{Y}}_6 \\ \hat{\mathbf{Y}}_7 \\ \hat{\mathbf{Y}}_8 \end{bmatrix} = \begin{bmatrix} \hat{\mathbf{R}}_{1,1} & \hat{\mathbf{R}}_{1,2} & \hat{\mathbf{R}}_{1,3} & \hat{\mathbf{R}}_{1,4} \\ 0 & \hat{\mathbf{R}}_{2,2} & \hat{\mathbf{R}}_{2,3} & \hat{\mathbf{R}}_{2,4} \\ 0 & 0 & \hat{\mathbf{R}}_{3,3} & \hat{\mathbf{R}}_{3,4} \\ 0 & 0 & 0 & \hat{\mathbf{R}}_{4,4} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \hat{\mathbf{X}}_1 \\ \hat{\mathbf{X}}_2 \\ \hat{\mathbf{X}}_3 \\ \hat{\mathbf{X}}_4 \end{bmatrix} \quad (12)$$

Using identical formulas presented in Equation (8), the transmitted signals are detected [5],[6].

III. System Description

A simulated single -user 4 x 4 D-BLAST spatially multiplexed LDPC encoded SC-FDMA Wireless Communication System as depicted in Figure 1 utilizes various signal detection schemes. . In such a communication system, a color image is encrypted with Chaos-Based Image Encryption Scheme [7].

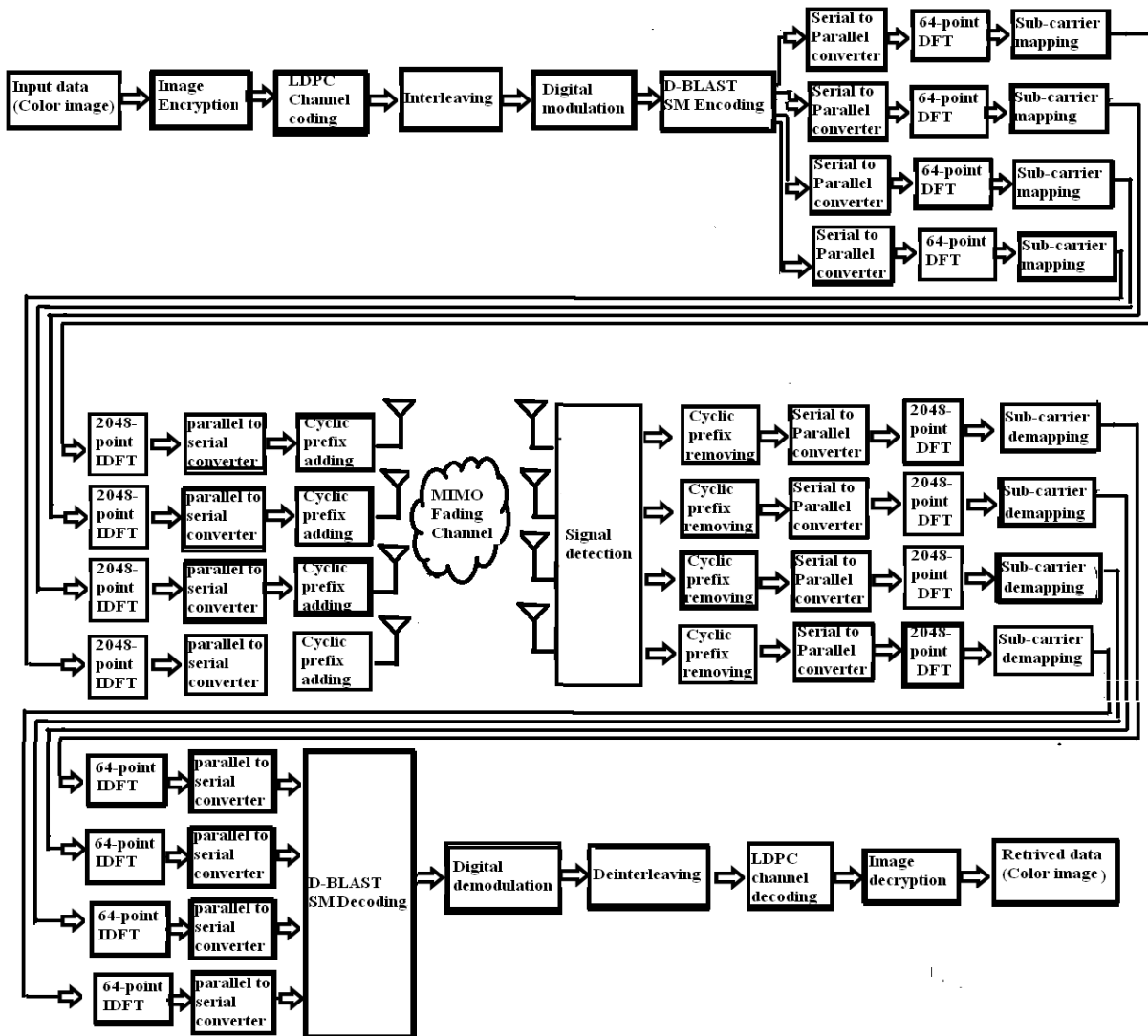


Figure 1: Conceptual Block diagram of D-BLAST aided LDPC encoded SC-FDMA Wireless Communication System

The encrypted data are channel encoded using low density parity check coding technique [8],[9] and interleaved for minimization of burst errors. The interleaved bits are digitally modulated using various types of digital modulations and spatially multiplexed using D-BLAST scheme to produce four independent data streams. Each data stream are serial to parallel converted, DFT-spreaded/precoded for enabling a low PAPR and subsequently subcarriers are mapped prior to OFDM modulation. The modulated complex symbols are cyclically prefixed, parallel to serial converted and transmitted. In receiving section, the transmitted signals are detected and processed cyclic prefix removal, serial to parallel conversion, OFDM demodulation, subcarrier demapping, DFT-despreaded/decoded, parallel to serial conversion and subsequently spatially demultiplexed under D-BLAST scheme. The demultiplexed data are digitally demodulated, deinterleaved, channel decoded and decrypted to recover the transmitted color image [10],[11].

IV. Result and Discussion

In this section, a series of simulation results have been presented graphically to illustrate the significant impact of various signal detection and merely LDPC channel coding techniques on reliable extraction of color image from a noisy and distortion producing channel. The simulation study has been made using **MATLAB 2014a** based on the parameters given in Table 1. In Figure 2, it is observable that the system performance is well defined and quite satisfactory under consideration of ZF-SIC signal detection and QAM digital modulation schemes. At a typical signal to noise ratio(SNR) value of 1dB, the estimated BER values are 0.0467, 0.049, 0.0236 and 0.0465 in case of MMSE,ZF, ZF-SIC and MMSE-SIC signal detection viz. the system performance improvements are 2.964049 dB, 2.793343 dB and 2.945409 dB respectively in ZF-SIC as compared to MMSE,ZF and MMSE-SIC. In case of identical signal and noise power, the rate of noise contamination in terms of bit error rate is 11.11 %. for QAM and ZF-SIC. In Figure3, it is noticeable that the system performance is almost identical in QPSK digital modulation.

Table 1 Summary of the Simulated Model Parameters

Data type	Color image: 96 × 96× 3 pixels
Channel coding	½.-rated irregular LDPC
No of complex modulated symbols in OFDM block	2048
No of complex modulated symbols in DFT-spreading/precoding	64
Size of parity-check matrix used in LDPC coding	64 × 128
Length of Cyclic prefixing in number of complex symbols	205
LDPC decoding Algorithm	Log Domain Sum-Product
Data Modulation	QPSK, DQPSK and QAM
Signal detection	Minimum-mean-square-error(MMSE) , Zero-Forcing (ZF), Zero-Forcing successive interference cancellation(ZF-SIC) and Minimum mean square error successive interference cancellation(MMSE-SIC)
Channel	AWGN and Rayleigh
Signal to noise ratio, SNR	0 dB- 5 dB

and other signal detection schemes. At zero dB, the noise contamination in terms of bit error rate is 15.00 % for QPSK and ZF-SIC which is comparatively greater than the case of QAM and ZF-SIC adaptation. In Figure 4, the performance gap between different signal detection scheme and DQPSK modulation is almost negligible. In DQPSK, the system performance has been detected to be a worst case as compared to other QAM and QPSK. At 0dB, the noise contamination in terms of bit error rate is found to have a value of 25.89 % for DQPSK and ZF-SIC which is significantly high. In Figure 5, the transmitted, encrypted and retrieved images have been presented under consideration of a typically assumed SNR value of 5dB. The estimated bit error rate is zero and image retrieval with transmitted image encryption are quite satisfactory. In Figure 6, the histograms of RGB to Gray converted transmitted, encrypted and retrieved color images at SNR value of 5dB have been presented. It is quite evident from the presented histograms that the transmitted and retrieved image is highly correlated and the encrypted image is highly uncorrelated with other images. The majority of the pixels have their grayscale values ranging from 80 -200 in case of transmitted and retrieved images. In case of gray converted encrypted image, a wide distribution of pixel values ranging from 5-250 is noticeable. In Figure 7, 3-dimensional shaded surface with contour plot for RGB to Gray converted transmitted, encrypted and retrieved images are shown which ratifies that the presently considered simulated system is quite acceptable for secure data transmission.

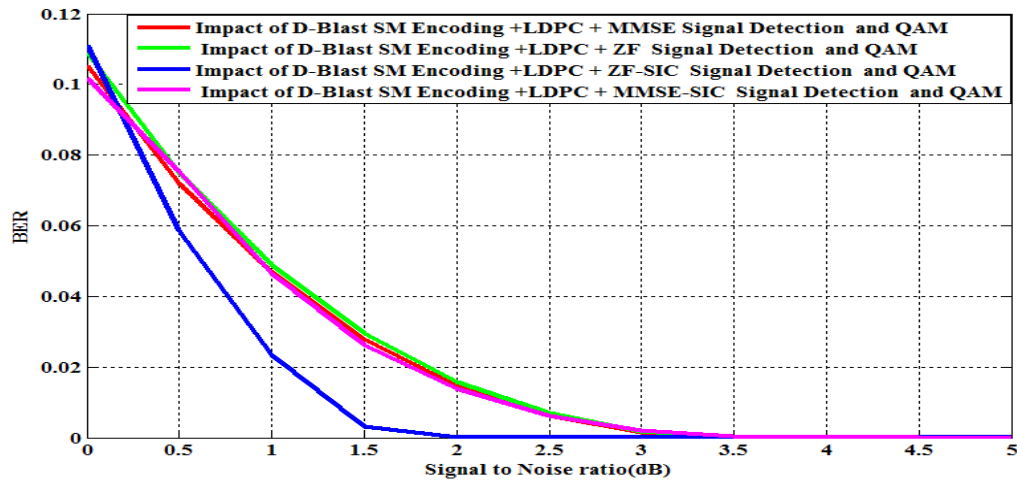


Figure 2: BER performance of a D-BLAST aided LDPC encoded SC-FDMA Wireless Communication System with implementation of various signal detection and QAM digital modulation scheme

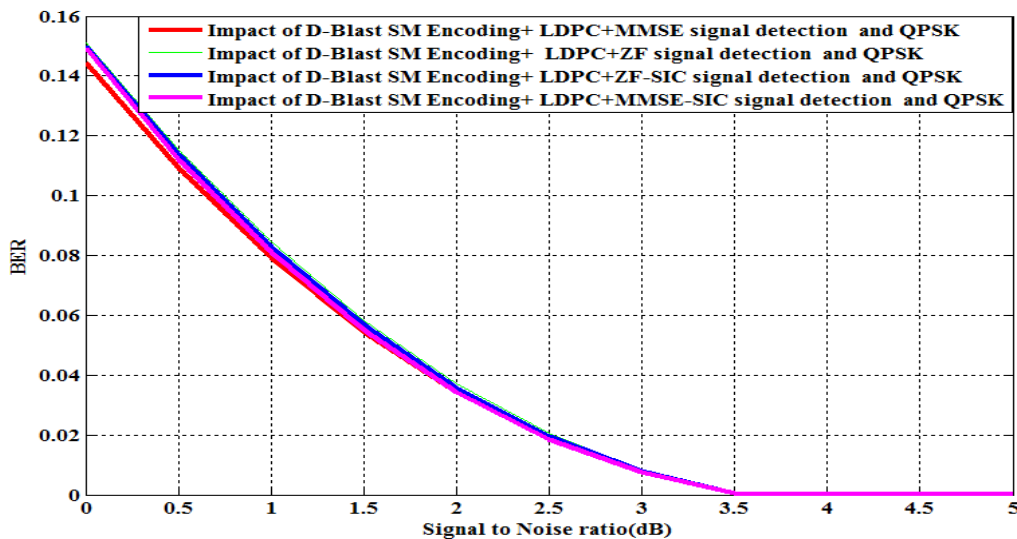


Figure 3: BER performance of a D-BLAST aided LDPC encoded SC-FDMA Wireless Communication System with implementation of various signal detection and QPSK digital modulation scheme

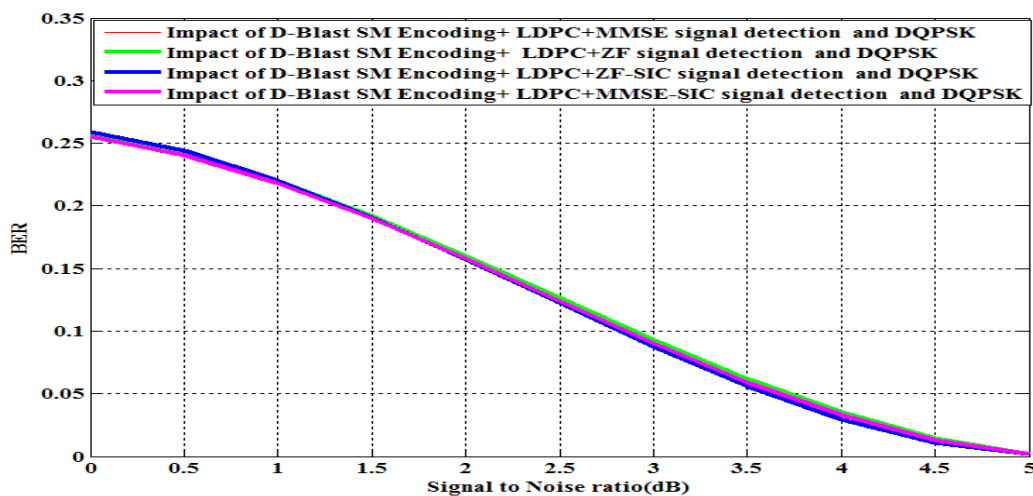


Figure 4: BER performance of a D-BLAST aided LDPC encoded SC-FDMA Wireless Communication System with implementation of various signal detection and DQPSK digital modulation scheme

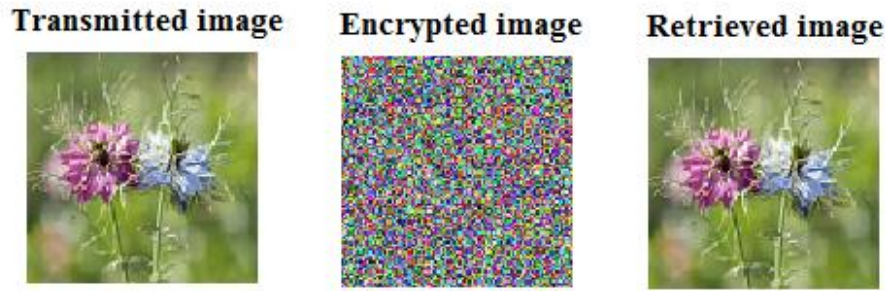


Figure 5: Pictorial views of transmitted , Encrypted and Retrieved image in a simulated D-BLAST aided LDPC encoded SC-FDMA Wireless Communication

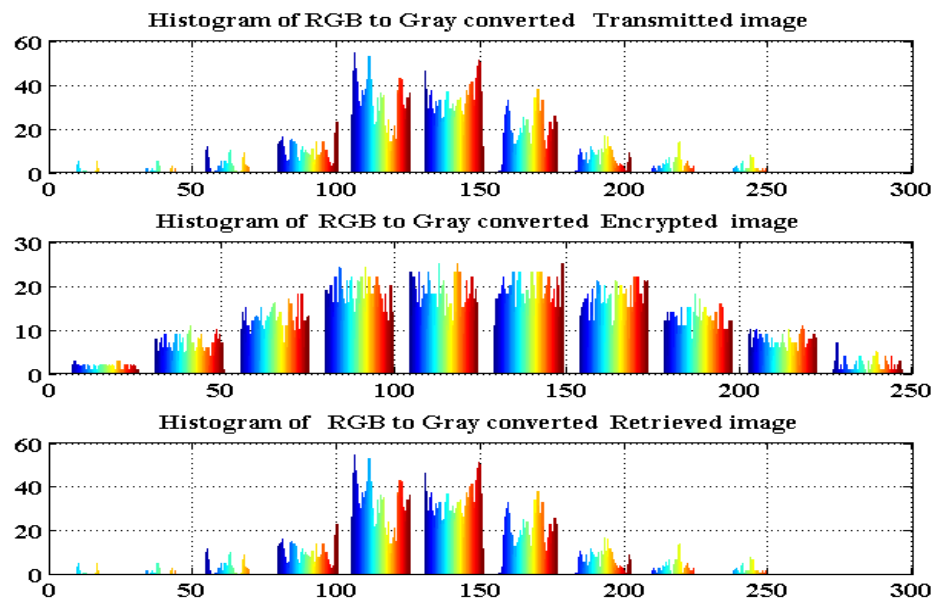


Figure 6: Histograms of transmitted, Encrypted and Retrieved image in a simulated D-BLAST aided LDPC encoded SC-FDMA Wireless Communication

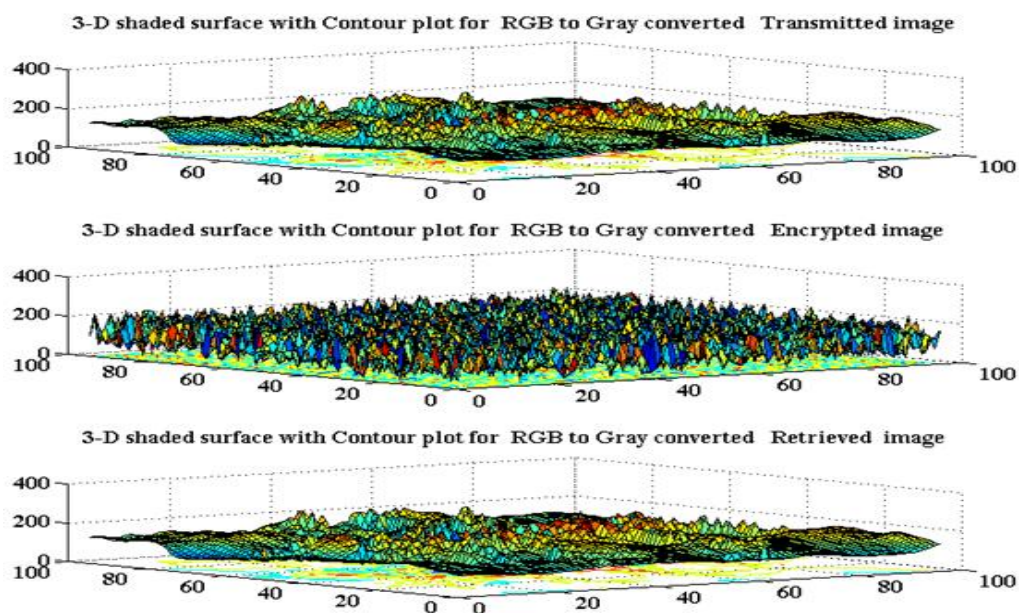


Figure 7: Three-dimensional shaded surface with Contour plot for RGB to Gray converted Transmitted, Encrypted and Retrieved images in a simulated D-BLAST aided LDPC encoded SC-FDMA Wireless Communication for a SNR value of 5dB.

V. Conclusions

In this paper, the performance of LDPC encoded SC-FDMA Wireless Communication System has been investigated using D-BLAST Spatial multiplexing(SM) Encoding and various signal detection techniques. The system performance results highlight the impact of various signal detection techniques on secure color image transmission. In the context of system performance, it can be concluded that the implementation of QAM digital modulation technique with deployment of ZF-SIC signal detection technique provides satisfactory result for such a LDPC encoded SC-FDMA wireless communication system.

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