Performance analysis of D-BLAST aided Turbo Encoded SC-FDMA wireless communication system

Md. Sarwar Hosain[1], Shaikh Enayet Ullah[2]and Rubaiyat Yasmin[3]
sarwar.iceru@gmail.com, enayet_apee@ru.ac.bd and sheba_ru@yahoo.com

[1]Department of Information and Communication Engineering
Pabna Universityof Engineeringand Technology, Pabna-6600, Bangladesh.

[2]Department of Applied Physics and Electronic Engineering
University of Rajshahi, Rajshahi-6205, Bangladesh.

[3]Department of Information and Communication Engineering
University of Rajshahi, Rajshahi-6205, Bangladesh.

Abstract:

In this paper, an effort has been to assess critically the performance of a punctured Turbo channel coded SC-FDMA wireless communication system under consideration of Diagonal Bell Laboratories Layered Space Time (D-BLAST) architecture. The proposed system under investigation adopts MIMO technique with 4 × 4 antenna configuration. Various channel equalization schemes such as Minimum mean square error (MMSE), Zero-Forcing (ZF), ZF-SIC, MMSE-SIC, Lattice Reduction-Based ZF and Lattice Reduction-Based MMSE Scheme have been used. From MATLAB based simulated study on *synthetically generated binary data transmission*, it is found that the system shows its improved and robust performance in perspective of QAM digital modulation and Lattice Reduction-Based MMSE Scheme.

Keywords: D-BLAST architecture, Turbo Coding, Channel Equalization scheme, Bit Error rate (BER), AWGN and Raleigh fading channels.

I. INTRODUCTION

MULTIPLE Input Multiple Output (MIMO) communications are generally referred to a collection of signal processing techniques that have been developed to enhance the performance of the wireless communication systems.MIMO techniques incorporates both spatial diversity and spatial multiplexing schemes and improve communications performance by either combating or exploiting multipath scattering in the communications channel between a transmitter and receiver. The use of MIMO techniques has been 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) with antenna configurations are of (4 × 4), (4 × 4), (2 × 2), (4 × 4), (8 × 8) and (8 × 8) respectively. 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) **[1]**

In 2014, Thu Nga Nguyen and et.al made performance evaluative study on Vertical Bell Laboratories Layered Space Time (V-BLAST) architecture based 2x2 multi user MIMO OFDMA wireless communication system. The results of their study confirm that the Zero Forcing (ZF) channel equalization aided VBLAST system shows a quite robust symbol error rate (SER) performance **[2]**. In 2013, Noman Akbar and et.al. made practical experimentation with a 2x2 Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) system on video signal transmission and showed that the ZF-VBLAST MIMO architecture used at the receiver side provided much better BER performance as compared to ZF channel equalization scheme[**3**].

It has been known that the SC-FDMA radio interface technology has practically adopted in both, LTE and LTE-Advanced system. The SC-FDMA has better performance with low-order digital modulations and it can provide larger cell coverage. With reduction of the PAPR of OFDM, the SC-FDMA enhances the power utilization efficiency of the MS batteries and prolongs their lifetimes[**4**].Based on the Diagonal Bell Laboratories Layered Space Time (D-BLAST) architectural concept presented[**5**], the present study investigates the performance of D-BLAST architecture with 4 x 4 antenna configuration for a Turbo encoded SC-FDMA wireless communication system .

II SIGNAL PROCESSING SCHEMES

In our presently considered 4 x 4 V-BLAST aided Turbo Encoded SC-FDMA wireless communication system, various signal processing schemes such as turbo channel coding, conventional, Lattice Reduction (LR) and Successive Interference Cancellation (SIC) basedchannel equalization schemes have been used. A brief description is given below.

A. TURBO CODING AND DECODING

Turbo codes are formed by concatenating in parallel two recursive systematic convolutional (RSC) codes separated by an interleaver. Apparently, the turbo code is a systematic code. Its coding rate is⅓ that is, for every input bit, the encoder produces three code bits. One is the message bit treated as systematic bit and the other two are the parity bits generated by the two RSC encoders. The code may also be punctured to obtain a coding rate of 1/2. Puncturing operates only on the parity sequences; the systematic bits are not touched.. In maximum a posteriori (MAP) turbo decoding, the transmitted message bits can be retrieved iteratively through computation of their log likelihood ratio (LLR).

Let $\overline{c} = c_0, c_1, c_2, c_3 \ldots\ldots\ldots\ldots c_{N-1}$ be a coded sequence produced by the rate-$\frac{1}{2}$ RSC encoder and

$\overline{r} = r_0, r_1, r_2, r_3 \ldots\ldots\ldots\ldots r_{N-1}$ be the noisy received sequencewhere the code word**is**

$$c_k = \left(c_k^{(1)}\ c_k^{(2)}\right)$$

with the first bit being the message bit and the second bit being the punctured parity bit. The corresponding received word is

$$r_k = \left(r_k^{(1)}\ r_k^{(2)}\right)$$

.

The coded bit 0/1 is converted to a value +1/-1. The maximum a posteriori (MAP) decoding is carried out as:

$$c_k^{(1)} = \left\{\frac{+1, \text{if} \quad P(c_k^{(1)} = +1 | \overline{r}) \geq P(c_k^{(1)} = -1 | \overline{r})}{-1, \text{if} \quad P(c_k^{(1)} = +1 | \overline{r}) < P(c_k^{(1)} = -1 | \overline{r})}\right\} (i = 0,1,2 \ldots N-1) \qquad (1)$$

A posteriori log likelihood ratio (LLR) of $c_k^{(1)}$ is given by

$$L\left(c_k^{(1)}\right) \triangleq \ln\left[\frac{P\left(c_k^{(1)} = +1 \middle| \overline{r}\right)}{P\left(c_k^{(1)} = -1 \middle| \overline{r}\right)}\right] \qquad (2)$$

The MAP decoding rule in Equation (1) can be presented alternatively as:

$$c_k^{(1)} = sign\left[L(c_k^{(1)} | \overline{r})\right] \qquad (3)$$

The magnitude of LLR, $| L(c_k^{(1)} | \overline{r}) |$ measures the likelihood of $c_k^{(1)}$=+1 or $c_k^{(1)}$=-1. The LLR can be expressed as a function of the probability $P(c_k^{(1)} = +1 | \overline{r})$[6]:

$$L\left(c_k^{(1)}\right) = \ln\left[\frac{P(c_k^{(1)} = +1 | \overline{r})}{P(c_k^{(1)} = -1 | \overline{r})}\right] = \ln\left[\frac{P(c_k^{(1)} = +1 | \overline{r})}{1 - P(c_k^{(1)} = +1 | \overline{r})}\right] \qquad (4)$$

B. CHANNEL EQUALIZATION SCHEMES

In your present study, transmitted signal X=[x1, x2, x3, x4]T , received signal Y=[y1,y2 y3,y4]T , white Gaussian noise N= [n1, n2 , n3, n4]T with variance σn2 and the channel matrix H=[h1 h2 h3 h4] have been considered. The signal model in terms of transmitted and received signals, Noise and channel coefficients can be written as:

$$Y = HX + N \qquad (5)$$

As the interference signals from other transmitting antennas are minimized to detect the desired signal, the detected desired signal from the transmitting antenna with inverting channel effect by a weight matrix W is given by

$$\tilde{X} = [\tilde{x}_1, \tilde{x}_2, \tilde{x}_3, \tilde{x}_4]^T = WY \qquad (6)$$

C. MINIMUM MEAN SQUARE ERROR (MMSE) SCHEME

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

$$W_{MMSE} = (H^H H + \sigma_n{}^2 I)^{-1} H^H \qquad (7)$$

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

$$\tilde{X}_{MMSE} = W_{MMSE} Y \qquad (8)$$

D. ZERO-FORCING (ZF) SCHEME

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

$$\mathbf{W_{ZF}} = \mathbf{(H^H H)^{-1} H^H} \qquad (9)$$

and the detected desired signal from the transmitting antenna is given by**[7]**

$$\tilde{X}_{ZF} = W_{ZF} Y \qquad (10)$$

E. ZF-SIC SCHEME

In ZF-SIC channel equalization scheme with 4× 4 antenna configuration, the channel matrix H undergoes QR factorization as

$$H = QR = Q\begin{bmatrix} R_{1,1} & R_{1,2} & R_{1,3} & R_{1,4} \\ \mathbf{0} & R_{2,2} & R_{2,3} & R_{2,4} \\ \mathbf{0} & \mathbf{0} & R_{3,3} & R_{3,4} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & R_{3,4} \end{bmatrix} \qquad (11)$$

where, Q and R are the unitary and upper triangular matrix respectively.Equation (5) can be rewritten on multiplying by $\mathbf{Q^H}$as

$$X = Q^H Y = RX + Q^H N \text{ (12)}$$

where, $Q^H N$ is a zero-mean complex Gaussian random vector. Since $Q^H N$ and N **have** the same statistical properties, $Q^H N$ can be used to denote **N**. We get Equation **(12)**as

$$X = RX + N$$

$$\Downarrow$$

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} = \begin{bmatrix} r_{1,1} & r_{1,2} & r_{1,3} & r_{1,4} \\ 0 & r_{2,2} & r_{2,3} & r_{2,4} \\ 0 & 0 & r_{3,3} & r_{3,4} \\ 0 & 0 & 0 & r_{4,4} \end{bmatrix} \begin{bmatrix} \tilde{x}_1 \\ \tilde{x}_2 \\ \tilde{x}_3 \\ \tilde{x}_4 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix} \quad (13)$$

the detected desired signal $\tilde{X}s$ from the four transmitting antennas can written on neglecting noise term from Equation **(13)** as

$$\left.\begin{aligned} \tilde{x}_4 &= \frac{x_4}{r_{4,4}} \\ \tilde{x}_3 &= \frac{(x_3 - r_{3,4}\tilde{x}_4)}{r_{3,3}} \\ \tilde{x}_2 &= \frac{(x_2 - r_{2,3}\tilde{x}_3 - r_{2,4}\tilde{x}_4)}{r_{2,2}} \\ \tilde{x}_1 &= \frac{(x_1 - r_{1,2}\tilde{x}_2 - r_{1,3}\tilde{x}_3 - r_{1,4}\tilde{x}_4)}{r_{1,1}} \end{aligned}\right| \quad (14)$$

F MMSE-SIC SCHEME

The received signal, channel matrix and noise are extendedas

$$H_{ex} = \left[H^T \sqrt{\frac{\sigma^2{}_n}{\sigma^2{}_s}} I \right]^T, \; Y_{ex} = \left[Y^T \quad 0^T \right] \text{ and}$$

$$N_{ex} = \left[N^T - \sqrt{\frac{\sigma^2{}_n}{\sigma^2{}_s}} X^T \right]^T \quad (15)$$

Where, $\frac{\sigma^2{}_n}{\sigma^2{}_s}$ is the ratio of average noise power to average signal power (1/SNR). On QR factorization of extended channel matrix H_{ex}, we get

$$H_{ex} = Q_{ex} . R_{ex} \quad (16)$$

Where, Qex and Rex represent a unitary matrix and an upper triangular matrix respectively. We assume that Y, H, N, Q and R are replaced by Yex, Hex, Nex, Qex and Rex respectively and correspondingly the resulting system takes the following form

$$X_{ex} = Q^H_{ex} . Y_{ex}$$

$$= R_{ex} . X_s + Q^H_{ex} . N_{ex} \quad (17)$$

Neglecting $Q^H_{ex} . N_{ex}$ term from Equation (17), the detected desired signal $\tilde{X}s_{ex}$ from the four transmitting antennas can written as

$$\left.\begin{aligned} \tilde{x}_{ex4} &= \frac{x_{ex4}}{r_{ex4,4}} \\ \tilde{x}_{ex3} &= \frac{(x_{ex3} - r_{ex3,4}\tilde{x}_{ex4})}{r_{ex3,3}} \\ \tilde{x}_{ex2} &= \frac{(x_{ex2} - r_{ex2,3}\tilde{x}_{ex3} - r_{ex2,4}\tilde{x}_{ex4})}{r_{2,2}} \\ \tilde{x}_{ex1} &= \frac{(x_{ex1} - r_{ex1,2}\tilde{x}_{ex2} - r_{ex1,3}\tilde{x}_{ex3} - r_{ex1,4}\tilde{x}_{ex4})}{r_{ex1,1}} \end{aligned}\right| \quad (18)$$

G LATTICE REDUCTION-BASED ZF SCHEME

In Lattice Reduction (LR) based ZF scheme, the complex valued channel matrix His initially undergone QR decomposition. After implementing Lenstra–Lenstra–LovKasz(CLLL) algorithm presented in Table 1, the lattice-reduced matrix G(=QR) and integer unimodular matrix T are obtained.

Table 1: Lenstra–Lenstra–LovKasz(CLLL) algorithm using MATLAB notation

```
INPUT :{H}
OUTPUT :{Q,R,T}
[ Q R ] $\leftarrow$ qr(H)
$\zeta \leftarrow$ size(H,2)
T $\leftarrow I_\zeta$
while $\rho \le \zeta$
    for l=1: ρ -1
        $\mu \leftarrow \lceil \mathbf{R}(\rho-l,\rho) / \mathbf{R}((\rho-l,\rho-l) \rfloor$
        if $\mu \neq 0$
            $\mathbf{R}(1:\rho-l,\rho) \leftarrow \mathbf{R}(1:\rho-l,\rho) - \mu\mathbf{R}(1:\rho-l,\rho-l)$
            $T(:,\rho) \leftarrow T_r(:,\rho) - \mu T(:,\rho-l)$
        end if
    end for
    if $\delta|(\mathbf{R}(\rho-1,\rho-1))|^2 > |(\mathbf{R}(\rho,\rho)|^2 + |(\mathbf{R}(\rho-1,\rho)|^2$
        Swap the (ρ-1)th and ρth columns in R and T
        $\theta = \begin{bmatrix} \alpha^* & \beta \\ -\beta & \alpha \end{bmatrix}$ with $\alpha = \frac{R(\rho-1,\rho-1)}{\|R(\rho-1:\rho,\rho-1)\|}$ and $\beta = \frac{R(\rho,\rho-1)}{\|R(\rho-1:\rho,\rho-1)\|}$
        $\mathbf{R}(\rho-1:\rho,\rho-1:\zeta) \leftarrow \theta\,\mathbf{R}(\rho-1:\rho,\rho-1:\zeta)$
        $Q(:,\rho-1:\rho) \leftarrow Q(:,\rho-1:\rho)\,\theta^T$
        $\rho \leftarrow \max\{(\rho-1,2\}$
    else
        $\rho \leftarrow \rho+1$
    end if
end while
```

The linear filter in case of LR-ZF channel equalization scheme usingcomputed lattice-reduced matrix G can be written as

$$W_{zf}^{H} = (G^{H}G)^{-1}G^{H} \quad (19)$$

The channelequalized signal can be written in terms of received signal Y and linear filter W_{zf}^{H} as

$$\hat{C}_{zf} = W_{zf}^{H}Y \quad (20)$$

The detected transmitted signal can be written as

$$\hat{S}_{zf} = T^{-1}\hat{C}_{zf} \quad (21)$$

H LATTICE REDUCTION-BASED MMSE SCHEME

In Lattice Reduction (LR) based MMSE scheme, the linear filter can be written in terms of noise variance ($\sigma^2{}_n$), signal power ($\sigma^2{}_s$), lattice-reduced matrix and integer unimodular matrix

$$W_{mmse}^{H} = (G^{H}G + \frac{\sigma^2{}_n}{\sigma^2{}_s}T^{-T}T^{-1})^{-1}G^{H} \quad (22)$$

The channelequalized signal can be written in terms of received signal Y and linear filter W_{mmse}^{H} as

$$\hat{C}_{mmse} = W_{mmse}^{H}Y \quad (23)$$

The detected transmitted signal can be written as [8]

$$\hat{S}_{mmse} = T^{-1}\hat{C}_{mmse} \quad (24)$$

III. COMMUNICATION SYSTEM MODEL

In this section, we present a series of simulation results to illustrate the significant impact of system performance in terms of BER in Coordinated Multiple Point transmission and reception. The Simulation study has been made using **MATLAB 2012a** based on the parameters given in Table 2.

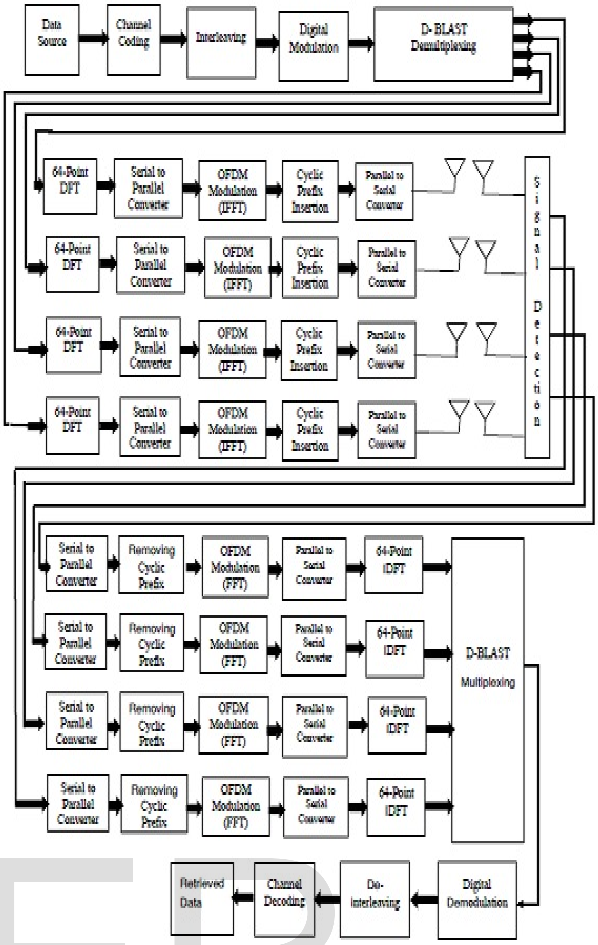

Figure 1: Block diagram of a D-BLAST aided Turbo Encoded SC-FDMA wireless communication system.

Table 2: Summary of the Simulated Model Parameters

no. of synthetically generated binary data used	2046
Channel Coding	Punctured Turbo coding with rate 1/2
Digital modulation	QAM , QPSK and DQPSK
No of subcarriers (FFT Size)	2048
CP length	205 symbols
Method used in Turbo decoding	Maximum a posteriori (MAP)
No of iterations considered in Turbo decoding	10
Antenna Configuration (User Equipment and Base station)	(4,4)
Signal Detection Scheme	MMSE,ZF, MMSE-SIC,ZF-SIC,LR-ZF and LR-MMSE
Channel	AWGN and Rayleigh fading
Signal to noise ratio (SNR)	0 to 5 dB

IV. RESULTS AND DISCUSSION

It is assumed that the channel state information (CSI) is available at the receiver and the fading process is approximately constant during whole transmission time. The graphical representations shown in Figure 2 through Figure 6are clearly indicative of system performance comparison with implementation of various channel equalization schemesunder various low order digital modulations. In Figure 2, it is quite noticeable that the BER performance differences are not quite obvious over a significant lower SNR value areas in case of MMSE,MMSE-SIC and ZF-SIC signal detection and QAM digital modulation schemes. At 1 dB and 2 dB SNRvalues, system performance gain of 0.60dB and 1.97dB are achieved in MMSE as compared to ZF respectively.At 5% BER, a SNR gain of 0.5 dB is obtained in MMSE as compared to ZF.

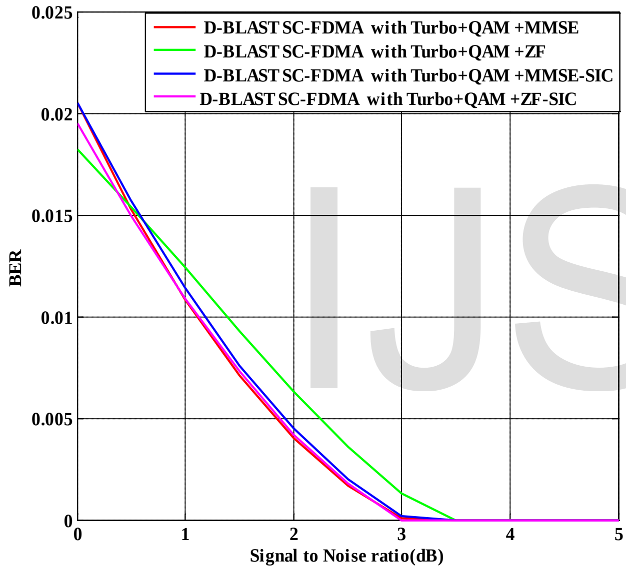

Figure 2: BER performance of Turbo encoded D-BLAST SC FDMA wireless communication system under deployment of various channel equalization and QAM digital modulation schemes.

In Figure 3, the system shows almost identical performance in case of ZF and MMSE. The system performance for the MMSE-SIC and ZF-SIC are well defined.The system shows quite satisfactory performance in ZF-SIC channel equalization and QPSK digital modulation schemes and a performance improved of 1.07 dB is provided in ZF-SIC as compared to MMSE-SIC at a typically assumed SNR value of 1dB.At 5% BER, a SNR gain of 0.28dB is obtained in ZF-SIC as compared to MMSE-SIC.In Figure 4, the system performance with DQPSK digital modulation are well defined in comparatively higher SNR values. It shows better performance in MMSE-SIC and unsatisfactory performance in ZF. In low SNR values, the system shows comparatively acceptable performance under MMSE. At 1 dB SNR value, a system gain of 0.16 dB and 0.24 dB are obtained in case of MMSE as compared to ZF and MMSE-SIC/ZF-SIC respectively.

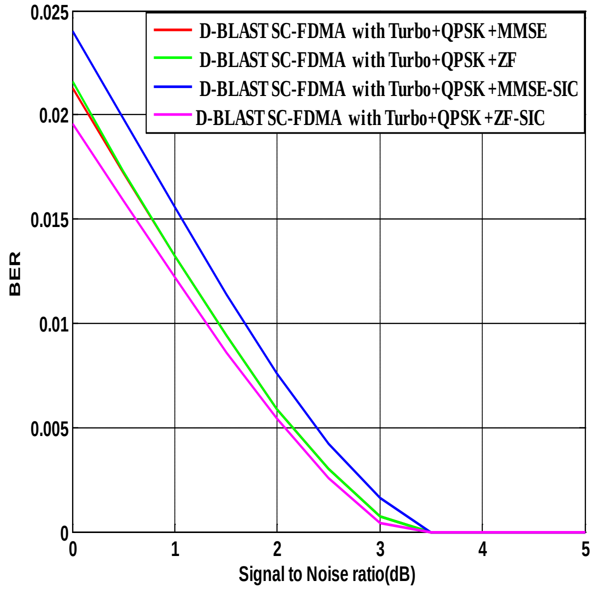

Figure 3: BER performance of Turbo encoded D-BLAST SC FDMA wireless communication system under deployment of various channel equalization and QPSK digital modulation schemes.

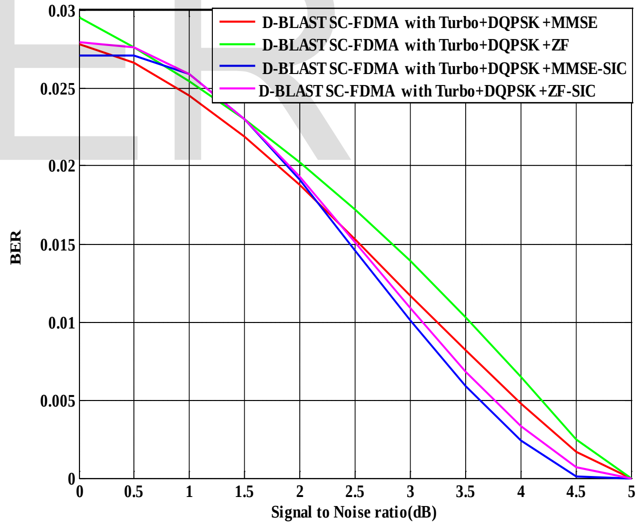

Figure 4: BER performance of Turbo encoded D-BLAST SC FDMA wireless communication system under deployment of various channel equalization and DQPSK digital modulation schemes.

In Figure 5 and Figure 6, the D-BLAST aided SC-FDMA system shows very much well defined performance with Lattice Reduction-Based ZF (LR-ZF) and Lattice Reduction-Based MMSE (LR-MMSE) Schemes. In Figure 5, the system shows robust performance in LR based ZF with QAM digital modulation as compared to DQPSK. At 1dB SNR value, a system performance enhancement of 3.69 dB is achieved in QAM as compared to DQPSK (BERs:0 .0109 and 0.0255). At 5% BER, a SNR gain of 4.17dB is obtained in QAM with LR-ZF as compared to DQPSK with LR-ZF. In

Figure 6, the system with LR-MMSE scheme shows better performance in QAM as compared to DQPSK. At atypically assumed SNR value of 1dB, a system performance gain of 3.57 dB is achieved in QAM as compared to DQPSK. At 5% BER, a SNR gain of approximately 4.00 dB is obtained in QAM with LR-MMSE as compared to DQPSK with LR-MMSE.

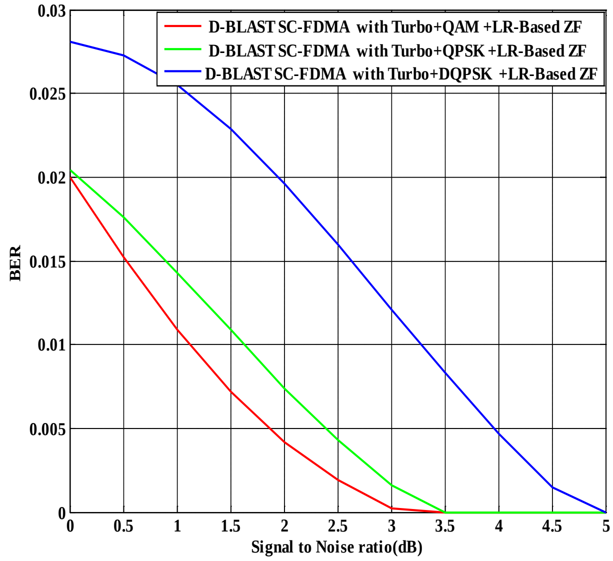

Figure 5: BER performance of Turbo encoded D-BLAST SC FDMA wireless communication system under deployment of Lattice Reduction-Based ZF Channel equalization and various digital modulation.

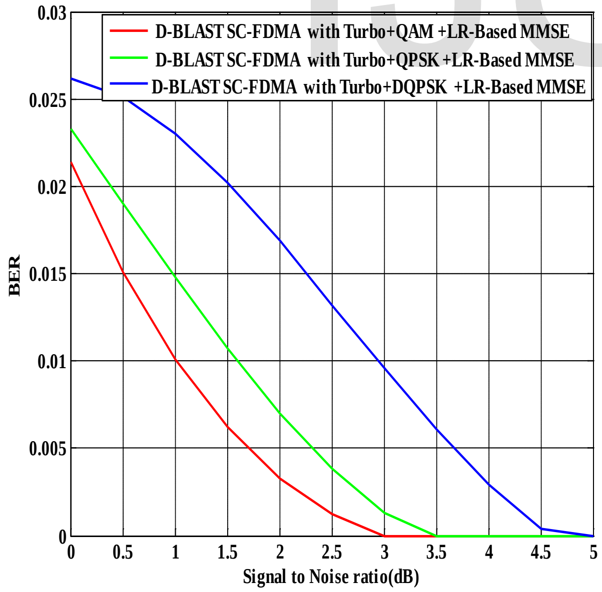

Figure 6: BER performance of Turbo encoded D-BLAST SC FDMA wireless communication system under deployment of Lattice Reduction-Based MMSE channelequalization and various digital modulation schemes.

V. CONCLUSION

In this paper, we have presented simulation results linking with the implementation of various channel equalization techniques in a Turbo encoded V-BLAST architectural configuration based SC-FDMA wireless communication system. The system performance results on the basis of various implemented channel equalization schemes give a clear indication of proper selecting receiver in such a simulated system. However, it can be concluded that the D-BLAST aided Turbo Encoded SC-FDMA wireless communication system is capable of showing improved and robust performance under implementation of low order QAM digital modulation and Lattice Reduction-Based MMSE Scheme.

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