BER Performance Analysis of a STBC Encoded Secured Multiuser MIMO-OFDM Wireless Communication System

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Abstract

*In this paper the BER performances are analyzed of a STBC encoded secured multiuser MIMO-OFDM wireless communication System. The 2X2 multi-antenna supported MIMO-OFDM system implements RSA cryptographic algorithm and ZF and MMSE based linear pre channel equalization schemes with deployment of various digital modulations (16-QAM, 16-PSK and 16-DPSK) over AWGN and Rayleigh fading channel. In this work the channel state information (CSI) is exploited at the transmitter side. It has been observed that the system under investigation outperforms with 16-QAM digital modulation and pre-MMSE channel equalization scheme and shows worst performance with 16-DPSK and pre-ZF. It is also observable that under situation of without implementing the pre channel equalization technique, the system provides satisfactory performance with 16-QAM and MMSE.***

Keywords: *MIMO-OFDM, STBC, CSI, MMSE, ZF*

1. Introduction

Communication systems using multiple antennas at the transmitter and/or the receiver have recently received increased attention due to their ability to provide substantial capacity improvements while achieving low error rate and/or high data rate by flexibly exploiting the attainable diversity gain and/or the spatial multiplexing gain [1]. Recently much attention has been paid on transmit diversity as an efficient technique to combat fading and simplify the implementation of mobile terminals [2]. Several methods in transmit diversity are proposed in [2-5]. Among them, Alamouti space-time block coding (STBC) [3] is very simple and attractive due to its advantages of not requiring feedback of channel state information and easy implementation. Space-time block codes (STBC) have been integrated with orthogonal frequency division multiplexing (OFDM) by implementing STBC at a block level in a structure commonly known as ST-OFDM [6]. Since wireless communications is challenged by limited spectral resources, multi-user spacial multiplexing has recently received considerable attention. Multi-user MIMO systems can significantly improve system throughput via transceiver signal processing if the number of transmit antennas is much larger than the number of receive antennas [7].

We shall consider the case of the simple Alamouti's space-time block code as it is the only scheme which can provide full rate and full diversity for any signal constellations. Among available multiuser detection techniques [8, 9] the most popular minimum mean square error (MMSE) method is chosen in [10, 11, 12] since it can provide good performance and can be readily implemented using standard adaptive algorithms. This MMSE multiuser detector is applied for Multiuser STBC-OFDM system in [10]. In [11] the BER values were estimated to show the impact of concatenated block code (RS, BCF, Cyclic code) and interleaver with

Space time trellies code (STTC) on the performance of MIMO-OFDM wireless communication system on the color image transmission with MMSE equalizer where the QAM digital modulation technique performed satisfactorily. [12] shows BER performance analysis for Zero-Forcing (ZF), Sphere Decoding (SD), Minimum mean square error (MMSE), signals detection schemes in a multi-user MIMO MCCDMA wireless communication system.

In this work we will address transmission techniques that exploit the channel state information (CSI) on the transmitter side. The CSI can be completely or partially known on the transmitter side. Sometimes, only statistical information on the channel state may be available. Exploitation of such channel information allows for increasing the channel capacity, improving error performance, while reducing hardware complexity [13]. In the 4X2 MIMO system, for example, exploitation of the complete CSI may improve the system capacity by as much as 1.5 bps/ Hz. In practice, however, full CSI may not be directly available due to feed back overhead and feedback delay. In particular, CSI for the time-varying channel cannot be tracked completely by the transmitter and thus, only partial information (e.g., the statistical information) can be exploited. In this work the BER performances are evaluated for zero-Forcing (ZF), Pre- ZF, minimum mean square error (MMSE) and pre-MMSE equalizers for multiuser MIMO-OFDM space time block coded wireless communication system.

2. Signal Detection Schemes

Consider a N_R X N_T MIMO system. Let H denote a channel matrix with it (j,i)th entry h_{ji} for the channel gain between the ith transmit antenna and the jth receiving antenna, j=1,2,…N_R and i=1,2,….N_T. The spatially-multiplexed user data and the corresponding received signals are represented by $\mathbf{x}=[\ x_1,\ x_2,\ \ldots\ldots x_{NT}]^T$ and $\mathbf{y}=[\ y_1,\ y_2,\ \ldots\ldots y_{NR}]^T$, respectively, where x_i and y_j denote the transmit signal from the ith transmit antenna and the received signal at the jth receive antenna, respectively. Let z_j denote the white Gaussian noise with a variance of σ^2_z at the jth receive antenna, and $\mathbf{h}_i$ denote the ith column vector of the channel matrix $\mathbf{H}$. Now, the N_R X N_T MIMO system is represented as [13]

$$\mathbf{y}=\mathbf{Hx}+\mathbf{z}$$

$$=\mathbf{h}_1x_1+\mathbf{h}_2x_2+\ldots\ldots+\mathbf{h}_{NT}x_{NT}+\mathbf{z} \tag{1}$$

Where $\mathbf{z}=[\ z_1,\ z_2,\ \ldots\ldots z_{NR}]^T$.

To facilitate the detection of desired signals from each antenna, the effect of the channel is inverted by a weight matrix **W** such that

$$\tilde{x}=[\tilde{x}_1,\tilde{x}_2,\tilde{x}_3\ldots\ldots\tilde{x}_{NT}]=Wy \tag{2}$$

that is, detection of each symbol is given by a linear combination of the received signals. The standard linear detection methods include the zero-forcing (ZF) technique and the minimum mean square error (MMSE) technique.

2.1. ZF Signal Detection

The zero-forcing (ZF) technique nullifies the interference by the weight matrix as given by [13]

$$\boldsymbol{W}_{ZF} = (\boldsymbol{H}^H\boldsymbol{H})^{-1}\boldsymbol{H}^H \tag{3}$$

Where $(\cdot)^H$ denotes the Hermitian transpose operation. In other words, it inverts the effect of channel as [13]

$$\begin{aligned}\tilde{x}_{ZF} &= W_{ZF}y \\ &= x + (H^H H)^{-1} H^H z \\ &= x + \tilde{z}_{ZF}\end{aligned} \tag{4}$$

Where, $\tilde{z}_{ZF} = W_{ZF}z = (H^H H)^{-1} H^H z$

2.2. MMSE Signal Detection

In order to maximize the post detection signal-to -interference plus noise ratio (SINR), the MMSE weight matrix is given as

$$\boldsymbol{W}_{MMSE} = (\boldsymbol{H}^H\boldsymbol{H} + \sigma^2_z \boldsymbol{I})^{-1}\boldsymbol{H}^H \tag{5}$$

Note that the MMSE receiver requires the statistical information of noises σ^2_z. It inverts the effect of channel as [13]

$$\begin{aligned}\tilde{x}_{MMSE} &= W_{MMSE}y \\ &= x + (H^H H + \sigma_z^2 I)^{-1} H^H z \\ &= x + \tilde{z}_{MMSE}\end{aligned} \tag{6}$$

Where $\tilde{z}_{MMSE} = W_{MMSE}z = (H^H H + \sigma_z^2 I)^{-1} H^H z$

2.3. Pre ZF and Pre MMSE Signal Detections

In general, a transmitter does not have direct access to its own channel state information. Therefore, some indirect means are required for the transmitter. In time division duplexing (TDD) system, we can exploit the channel reciprocity between opposite links (downlink and uplink). Based on the signal received from the opposite direction, it allows for indirect channel estimation. In frequency division duplexing (FDD) system, which usually does not have reciprocity between opposite directions, the transmitter relies on the channel feedback information from the receiver. In other words, CSI must be estimated at the receiver side and then, fed back to the transmitter side. CSI can be exploited at the transmitter with the channel gain of $H \in \mathbb{C}^{N_R X\, N_T}$ with $N_R \geq N_T$. Among various possible methods that use CSI for the spatial-multiplexing system, we will focus on the linear pre-equalization method. It employs pre-equalization on the transmitter side. The pre-equalization can be represented by a pre-equalizer weight matrix $W \in \mathbb{C}^{N_R X\, N_T}$ and thus, the precoded symbol vector $x \in \mathbb{C}^{N_T X 1}$ can be represented as [13]

$$x = W\tilde{x} \tag{7}$$

where $\tilde{x}$ is the original symbol vector for transmission. In case where the zero -forcing (ZF) equalization is employed, the corresponding weight matrix (assuming that the channel matrix is square) is given as

$$W_{ZF}=\beta H^{-1} \tag{8}$$

Where β is a constant to meet the total transmitted power constraint after pre-equalization and it is given as

$$\beta=\sqrt{\frac{N_T}{Tr(H^{-1}(H^{-1})^H)}} \tag{9}$$

To compensate for the effect of amplification by a factor of β at the transmitter, the received signal must be divided by β via automatic gain control (AGC) at the receiver. The received signal y is given by

$$\begin{aligned} y&=\frac{1}{\beta}(HW_{ZF}\tilde{x}+z) \\ &=\frac{1}{\beta}(H\beta H^{-1}\tilde{x}+z) \\ &=\tilde{x}+\frac{1}{\beta}z \\ &=\tilde{x}+\tilde{z}. \end{aligned} \tag{10}$$

In this case of pre MMSE equalization the weight matrix is given as

$$W_{MMSE}=\beta H^H(HH^H+\frac{\sigma_z^2}{\sigma_x^2}I)^{-1} \tag{11}$$

where the constant β is used again to meet the total transmitted power constraint and given by

$$\beta=\sqrt{\frac{N_T}{Tr\left[\left\{H^H(HH^H+\frac{\sigma_z^2}{\sigma_x^2}I)^{-1}\right\}\left\{H^H(HH^H+\frac{\sigma_z^2}{\sigma_x^2}I)^{-1}\right\}^H\right]}} \tag{12}$$

3. The Communication System Model

The MIMO wireless communication system under consideration is shown in Figure 1 where the CSI (Channel State Information) is exploited at the transmitter. In such a communication system, four users are simultaneously transmitting their text messages secretly. For secret message transmission the most widely used public-key cryptosystem RSA is used here [14]. After encryption of plaintext of each user the ciphertext is converted into binary messages. The transmitted bits of each individual user are channel encoded by a convolutional encoder of rate r = 1/2, interleaved for minimization of burst errors and then converted to M-ary signal. This M-ary signal is modulated using various types of modulation technique such as quadrature amplitude modulation (QAM), phase shift keying (PSK) and differentially phase shift keying (DPSK). The modulated digital signals are fed into the Space

Time Block Encoder using Alamouti scheme. 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 Lcp (0.1*1024) containing a copy of the last Lcp samples of the parallel –to- serial converted output of the 1024-point IFFT is added with the each OFDM symbol. The CP is essentially a guard interval which serves to eliminate interference between OFDM symbols [12].

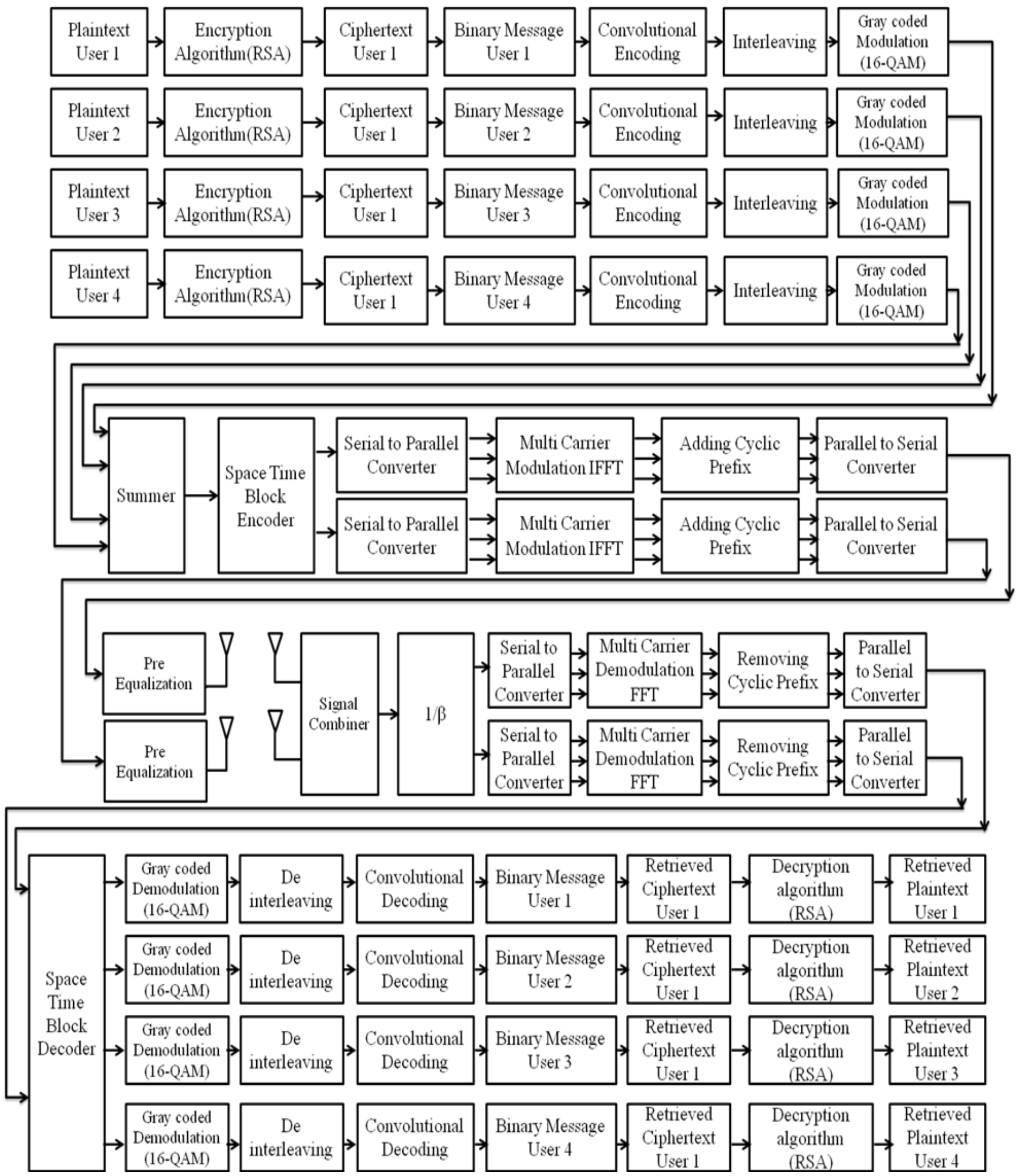

Figure 1. Block Diagram of FEC Encoded Secured Multi user Space Time Block Coded MIMO OFDM Wireless Communication System

However, the resulting OFDM symbols of length 1024+Lcp are lunched from the two transmitting antenna after pre equalization. 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. The complex symbols are now digitally demodulated, de interleaved, convolutionally decoded and decrypted to recover the transmitted data for each of the four users.

4. Performance Comparison and Result

The computer simulation has been conducted to evaluate the BER performance of the STBC encoded secured multiuser MIMO OFDM wireless communication system based on the parameter given in Table 1. The channel state information (CSI) is assumed to be available both at the receiver and the transmitter. Figure 2 through figure 5 shows the BER performance with implementation of both Pre and Post ZF and MMSE based channel equalization schemes and M-ary digital modulation techniques (16-QAM, 16-PSK, and 16-DPSK). In all cases, the present simulated system outperforms in 16-QAM modulation technique and shows worst performance in 16-DPSK.

Table 1. Simulated Model Parameters

Type of input signal for the users	Secured Text Messages
Public key for user 1	{5,119}
Private key for user 1	{77,119}
Public key for user 2	{7,187}
Private key for user 2	{23,187}
Public key for user 3	{11,221}
Private key for user 3	{35,221}
Public key for user 4	{13,85}
Private key for user 4	{5,85}
No. of Transmitting and Receiving antennas	2X2
Channel coding	½ rated Convolutional Encoding
Digital Modulation Techniques	16-QAM, 16-PSK and 16- DPSK
No. of OFDM subcarriers	1024
CP length	103 symbols
Signal Detection Scheme	ZF, Pre- ZF, MMSE and Pre-MMSE
Channel	AWGN and Rayleigh Fading channel
Signal to noise ratio(SNR)	0 to 10 dBs

It is observable in Figure 2 that under deployment of ZF channel equalization technique for a typically assumed BER values of 10^{-1}, the required SNR values are found to be of 3.5 dB, 9.1 dB and above 10dB respectively in case of 16-QAM, 16-PSK and 16- DPSK digital modulation techniques. In Figure 3, it is also observable that the BER values are 0.0918 and 0.4188 for a SNR value of 5dB in case of 16-QAM and 16-DPSK viz. the system performance is improved by 15.17 dB. In Figure 4, it is seen that the system shows almost identical performance in 16-QAM and 16-PSK over a significant area of SNR values. In Figure 5, the system shows distinct BER performance in different digital modulations. For a typical SNR value of 5dB, the BER values are 0.0676 and 0.4635 in case of 16-QAM and 16-DPSK, which is indicative of system performance improvement by 19.25 dB. On critical inspection of the graphical illustrations present in Figure 6, it is quite obvious that the system provides most satisfactory performance in Pre-MMSE and 16-QAM. Eventually an effort has been made to present both transmitted and retrieved text messages in Figure 7(a) through 7(b) for a SNR value of 6dB. The erroneous characters in the retrieved text messages are shown in bold faces (Figure 7).

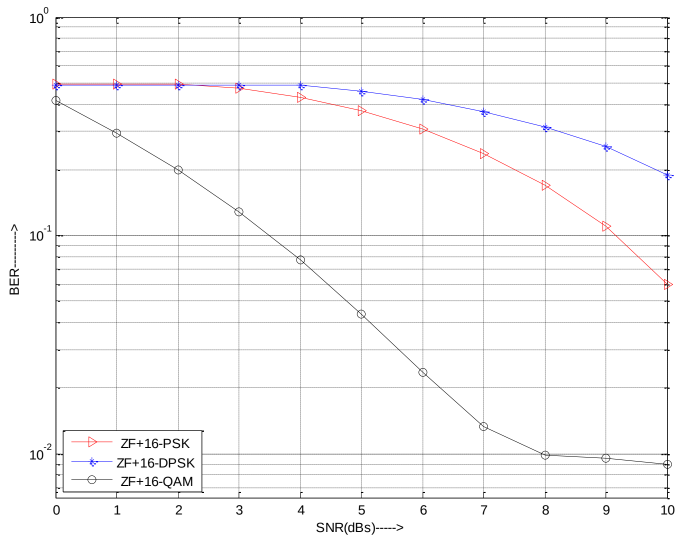

Figure 2. BER Performance Analysis for ZF Signal Detection Scheme

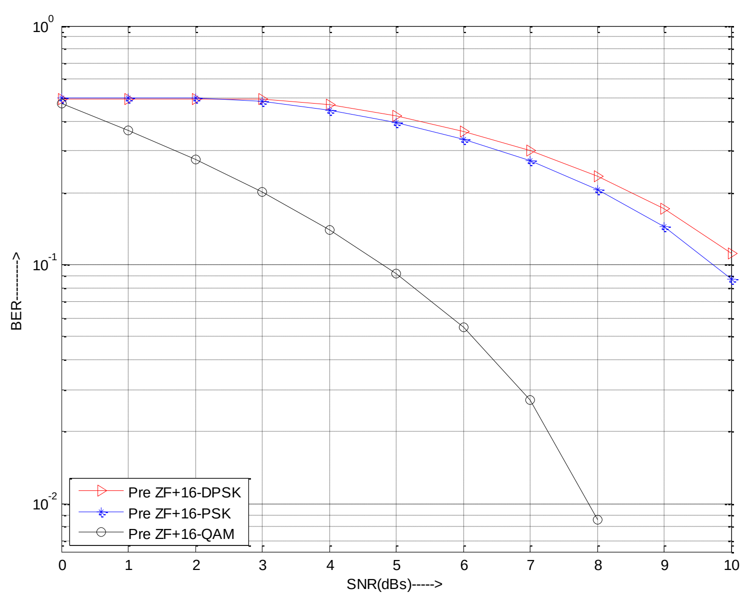

Figure 3. BER Performance Analysis for pre ZF Signal Detection Scheme

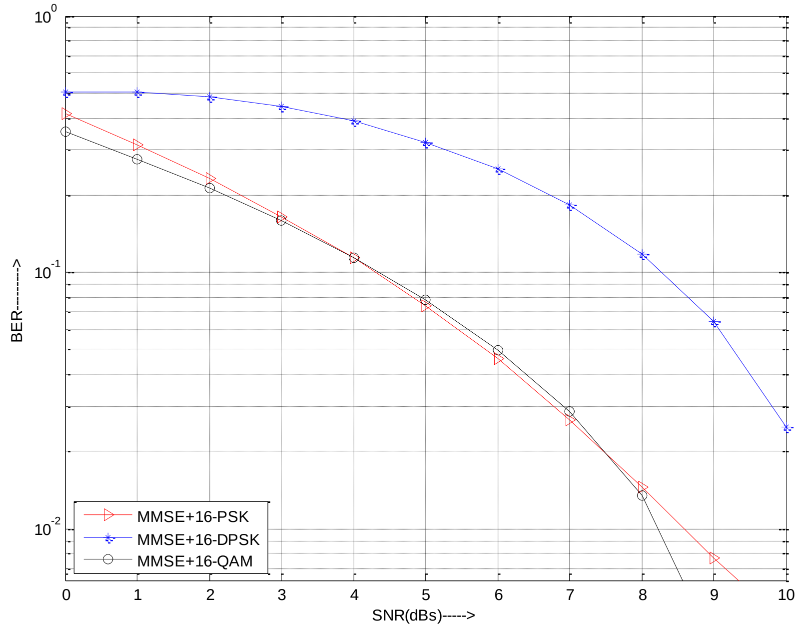

Figure 4. BER Performance Analysis for MMSE Signal Detection Scheme

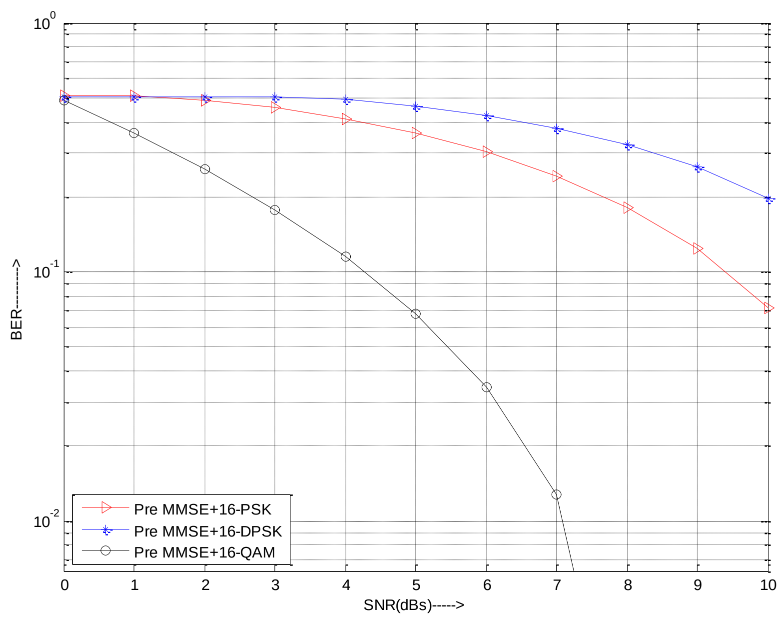

Figure 5. BER Performance Analysis for Pre MMSE Signal Detection Scheme

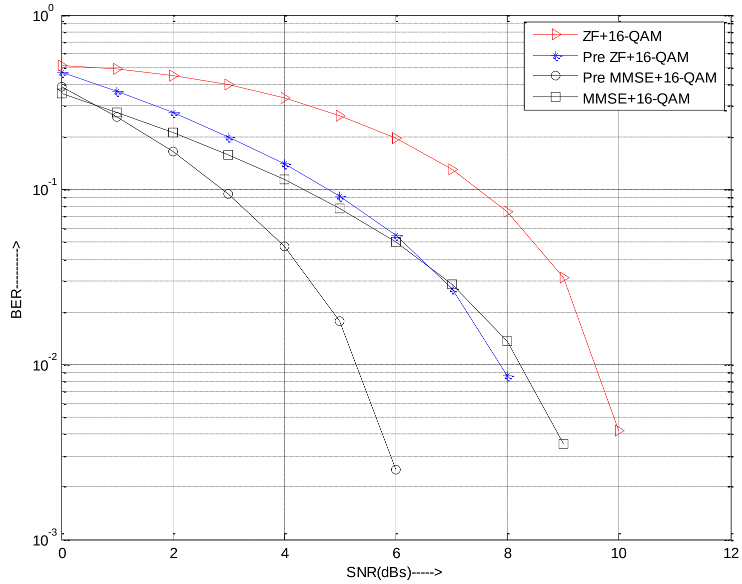

Figure 6. BER Performance Analysis for ZF, Pre ZF, MMSE and Pre MMSE Signal Detection Schemes for 16-QAM

Transmitted Plaintext for user1: Cryptography is the most important aspect of communication systems security.
Transmitted Plaintext for user2: Wireless communications is the fastest growing segment of the communications industry.
Transmitted Plaintext for user3: Communication systems are designed to transmit information bearing waveforms to the receiver.
Transmitted Plaintext for user4: If there were no noise, messages can be sent electronically to the outer limits of the universe by using small amount of power.

(a)

Retrieved Plaintext for user1: Cryptog**u** phy is the most importan**8·** spect of **c** mmunication systams security.
Retrieved Plaintext for user2: **Xi¬ele¢¢** communications is the f¬stest growing segment of the communications industr .
Retrieved Plaintext for user3: Communication systems are designed to transmit information bearing waveforms to the receive**g**
Retrieved Plaintext for user4: If there were no n **}**se,messages can be sent electronically to the outer l**:**mits of the un ve **0** by using small **a|** **U.t** of power

(b)

Figure 7. Transmitted Secured Text Messages (a) and Received Secured Text Messages under Rayleigh Fading Channel at 6dB SNR (b)

5. Conclusion

In this work, we have presented simulation results concerning the adaptation of various signal detection schemes in a STBC encoded secured multiuser MIMO OFDM wireless communication system. A range of system performance results highlight the impact of signal detection scheme on secured text massage transmission. On the basis of the results obtained in the present simulation based study, it can be concluded that under the implementation of 16-QAM digital modulation technique with pre MMSE signal detection scheme, the simulated MIMO OFDM system provides quite satisfactory performance.

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