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Performance Analysis of Slantlet Transform in MC-CDMA system

[1]Muhammad Umair, [2]Muhammad Adnan Khan, [3]Muhammad AamerSaleem Choudhry

[1, 2]School of Engineering and Applied Science, ISRA University, Islamabad Campus

[3]Department of Electrical Engineering, University of Lahore, Islamabad Campus

E-mail: [1]umairbwp@live.com, [2]adnan_600@yahoo.com, [3]aamer.dr@gmail.com

ABSTRACT

A Slantlet Transform based Space Time Block Coded Multi Carrier Code Division Multiple Access (SLT-STBC-MC-CDMA) system is proposed in this paper. We used two filters for detecting the odd and even index symbols as in STBC. These two filters are independently updated. These filters are analysed for flat fading channel (FFC) and selective fading channel (SFC) at different Doppler shift. The proposed scheme gives attractive bit error rate (BER) in FFC at different Doppler shift for all signal to noise ratio (SNR) with respect to Fast Fourier Transform (FFT) based STBC-MC-CDMA system. While in SFC, the proposed scheme gives low BER up to medium SNR. However, its performance degrades with respect to FT-STBC-MC-CDMA system at high SNR. It is also revealed that proposed scheme saves bandwidth as cyclic prefixes are not added.

Keywords:*SLT, MC-CDMA, STBC, BER, Bandwidth*

1. INTRODUCTION

The demand of high data rate is one of the key research areas of future networks. The multi-carrier transmission schemes like orthogonal frequency division multiplexing (OFDM), multi carrier code division multiple access (MC-CDMA) and multi carrier direct sequence (MC-DS)-CDMA are considered to be the strongest systems for fulfilling the high data rate demand of future networks. We used MC-CDMA system in this paper.

The MC-CDMA system works by combining frequency domain spreading and OFDM [1]. This is a useful technique for future generation networks in which high data rates and secure communication are priorities.

The MC-CDMA systems not only eliminate ISI but also accomplish the multi-path [2]. The performance of this system is analysed in [3] as well. The orthogonal wavelet based MC-CDMA system instead of Fourier transform (FT) in [4]. It was noted that such systems are capable of minimizing the inter symbol interference (ISI) and inter channel interference (ICI).

The FFT-OFDM systems are taking good attention for elimination of ISI and ICI. The cyclic prefixes are added to overcome ISI and ICI in such systems. This takes 25 percent more bandwidth. The discrete wavelet transforms (DWT) based OFDM system was proposed in [5-6] in order to utilize bandwidth efficiently and reduce ICI and ISI. DWT-MC-CDMA systems efficiently combat narrow band interference and are more robust to ICI than FFT based MC-CDMA (FFT-MC-CDMA) systems as shown in [7-10].

We proposed Slantlet transform based Space Time Block Coded MC-CDMA (SLT-STBC-MC-CDMA) system in this paper. The performance comparison of SLT-STBC-MC-CDMA and Fast Fourier Transform based Space Time Block Coded (FFT-STBC-MC-CDMA) is studied for two different models: flat fading channel (FFC) and selective fading channel (SFC) at different Doppler shifts. This proposed scheme gives attractive low bit error rate in FFC for all signals to noise ratio (SNR) as compare to FFT-STBC-MC-CDMA system. In SFC, the SLT-STBC-MC-CDMA system gives low bit error rate up to medium SNR. However, its performance degrades at high SNR as compare to FFT-STBC-MC-CDMA system.

The study of this proposed scheme reveals that the SLT-STBC-MC-CDMA system can be used instead of FFT-STBC-MC-CDMA system in order to achieve the high data rate and save bandwidth in communication for slowly moving objects.

This paper is organised as: In section 2, the system model of proposed scheme is presented. In section 3, a briefly explanation of Slantlet Transform is given. In section 4, the cost function is presented. In section 5, the simulation results are discussed. In section 6, a brief conclusion of the paper is given.

2. SYSTEM MODEL

The figure 1 represents the transmitter structure of Slantlet transform based MC-CDMA system. We use two transmit and one receive antenna for ease. The Alamouti's space time coding is applied for every two consecutive symbols. The symbols $c_k(2i-1)$ and $c_k(2i)$ are sent by transmit antenna A and B in first symbol interval. The symbols $c_k^*(2i-1)$ and $-c_k^*(2i)$ are sent by transmit antenna A and B in next symbol interval A spreading code pair $(\mathbf{d}_{k,1}, \mathbf{d}_{k,2})$ is used additionally in antenna's A and B. They are of form

$$\mathbf{d}_{k,n} = [d_{k,n,1}, d_{k,n,2}, d_{k,n,3}, \dots, d_{k,n,N}] \quad (1)$$

In next step, the N-point inverse Slantlet transform (ISLT) operation is performed with N is number of sub-carriers. The Slantlet transform details are given in section 4. The ISLT output is parallel to serial converted. There is no

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need of cyclic prefix addition in Slantlet transform like Fourier transform. This output is simply transmitted through the channel.

The figure 2 represents Slantlet transform based MC-CDMA receiver. The received signal is serial to parallel converted. Then, N point Slantlet transform (SLT) operation is performed on the received data. The SLT received data vector is written as:

$$\mathbf{r}(2i-1)=\sum_{k=1}^{K}\left\{\mathbf{H}_{k,1}\mathbf{d}_{k,1}\mathbf{c}_k(2i-1)+\mathbf{H}_{k,2}\mathbf{d}_{k,2}\mathbf{c}_k(2i)\right\}+\boldsymbol{z}(2\mathrm{i}-1) \tag{2}$$

$$\mathbf{r}(2i)=\sum_{k=1}^{K}\{-\mathbf{H}_{k,1}\mathbf{d}_{k,1}\mathbf{c}_k^*(2i)+\mathbf{H}_{k,2}\mathbf{d}_{k,2}\mathbf{c}_k^*(2i-1)\}+\boldsymbol{z}(2i) \tag{3}$$

with$\mathbf{H}_{k,n}$is the Slantlet transform domain channel response from *nth* transmit antenna of user *k.*

$$\mathbf{H}_{k,n}=diag(\mathbf{H}_{k,m,0},\mathbf{H}_{k,m,1},\dots,\mathbf{H}_{k,m,N-1}) \tag{4}$$

and $z(l)$ is the additive white Gaussian noise with zero mean and covariance matrix $\sigma_z^2 I_{2N}$;I_{2N} is the identity matrix of dimensions $2N\times 2N$.

The useable spreading code at *nth* transmit antenna of user *k*is $\mathbf{m}_{k,n}$. Then (2) and (3) can be rewritten like

$$\mathbf{r}(2i-1)=\sum_{k=1}^{K}\left\{\mathbf{m}_{k,1}\mathbf{c}_k(2i-1)+\mathbf{m}_{k,2}\mathbf{c}_k(2i)\right\}+\boldsymbol{z}(2\mathrm{i}-1) \tag{5}$$

$$\mathbf{r}(2i)=\sum_{k=1}^{K}\left\{-\mathbf{m}_{k,1}\mathbf{c}_k^*(2i)+\mathbf{m}_{k,2}\mathbf{c}_k^*(2i-1)\right\}+\boldsymbol{z}(2i) \tag{6}$$

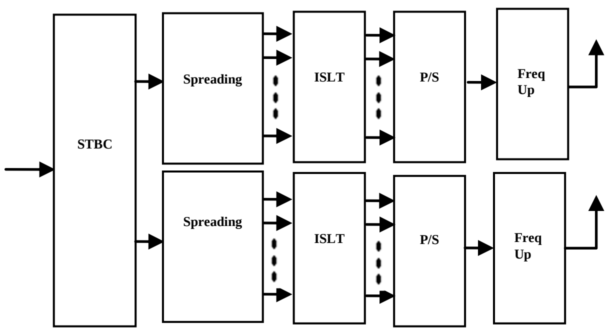

Fig.1. SLT-STBC- MC-CDMA Transmitter

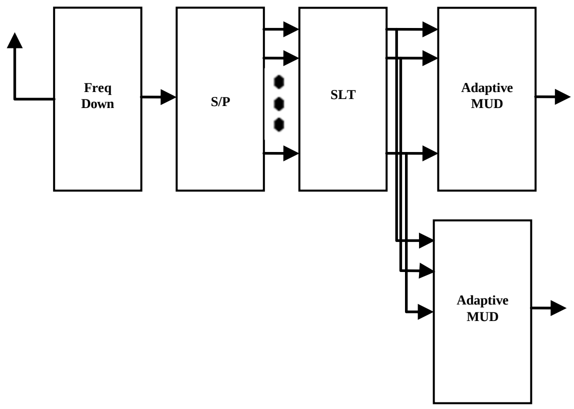

Fig. 2. SLT-STBC- MC-CDMA Receiver

3. SLANTLET TRANSFORM [4]

The Slantlet transform was proposed by Selesnick in 1999. It is necessary to consider a discrete wavelet transform (DWT) based filter bank. The filters length must be shorter which satisfy the orthogonality and zero moment condition. Daubechies describes the shortest filter with *k* zero mean moments in [1].

The filters *F(z)* and *H(z)* has a length of 4 for *k* = 2 zero moment. The iterated filters are of length 10 and 4. The orthogonal filter bank with *k* = 2 zero moment can be obtained with the filter lengths 8 and 4 without constraint that filter are products. There is the reduction of two samples that grows with the number of stages. This reduction in length with maintained orthogonality and moment properties is possible as proved in this paper.

The filter coefficients derived in paper are given below

$$G_1(z)=\left(-\frac{\sqrt{10}}{20}-\frac{\sqrt{2}}{4}\right)+\left(\frac{3\sqrt{10}}{20}+\frac{\sqrt{2}}{4}\right)z^{-1}+\left(-\frac{3\sqrt{10}}{20}+\frac{\sqrt{2}}{4}\right)z^{-2}+\left(\frac{\sqrt{10}}{20}-\frac{\sqrt{2}}{4}\right)z^{-3} \tag{7}$$

$$F_2(z)=\left(\frac{7\sqrt{5}}{80}-\frac{3\sqrt{55}}{80}\right)+\left(-\frac{\sqrt{5}}{80}-\frac{\sqrt{55}}{80}\right)z^{-1}+\left(-\frac{9\sqrt{5}}{80}+\frac{\sqrt{55}}{80}\right)z^{-2}+\left(-\frac{17\sqrt{5}}{80}+\frac{3\sqrt{55}}{80}\right)z^{-3}+\left(\frac{17\sqrt{5}}{80}+\frac{3\sqrt{55}}{80}\right)z^{-4}+\left(\frac{9\sqrt{5}}{80}+\frac{\sqrt{55}}{80}\right)z^{-5}+\left(\frac{\sqrt{5}}{80}-\frac{\sqrt{55}}{80}\right)z^{-6}+\left(-\frac{7\sqrt{5}}{80}-\frac{3\sqrt{55}}{80}\right)z^{-7} \tag{8}$$

$$H_2(z)=\left(\frac{1}{16}+\frac{\sqrt{11}}{16}\right)+\left(\frac{3}{16}+\frac{\sqrt{11}}{16}\right)z^{-1}+\left(\frac{5}{16}+\frac{\sqrt{11}}{16}\right)z^{-2}+\left(\frac{7}{16}+\frac{\sqrt{11}}{16}\right)z^{-3}+\left(\frac{7}{16}-\frac{\sqrt{11}}{16}\right)z^{-4}+\left(\frac{5}{16}-\frac{\sqrt{11}}{16}\right)z^{-5}+\left(\frac{3}{16}-\frac{\sqrt{11}}{16}\right)z^{-6}+\left(\frac{1}{16}-\frac{\sqrt{11}}{16}\right)z^{-7} \tag{9}$$

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Some of the SLT filter bank features are two zero moments and orthogonality. These filter banks also observes octave band features such that upper band frequency is twice the lower band frequency. The filter banks dilate by a factor of two and decays with multi decisions. These filters are also linear. There is no way of implementation for SLT. They are implemented in iterative DWT filter bank. So DWT and SLT have same computational complexity.

The figure 1 and 2 represents the transmitter and receiver of SLT-MC-CDMA. It is similar to FFT-MC-CDMA system. The only major difference is that the cyclic prefixes are not added in SLT-MC-CDMA system due its very high orthogonal property. This also saves the bandwidth. Therefore, It can be said that spectral efficiency and data rate of SLT-MC-CDMA system is very attractive than FFT-MC-CDMA system.

4. COST FUNCTION

The Minimum Mean Square Error (MMSE) based cost function was proposed in [11] and [12]. The Mean Square Error (MSE) based cost function given by

$$J(\mathbf{w}_1, \mathbf{w}_2) = E[|\mathbf{w}^H \mathbf{r}(i) - \mathbf{c}_1(i)|^2]$$

$$= E[|\mathbf{w}_1^H \mathbf{r}(i) - \mathbf{c}_1(2i-1)|^2] + E[|\mathbf{w}_2^H \mathbf{r}(i) - \mathbf{c}_1(2i)|^2]$$

$$= J(\mathbf{w}_1) + J(\mathbf{w}_2) \quad (10)$$

where $\mathbf{W} = [\mathbf{w}_1 \mathbf{w}_2]$ and

$$J_1(\mathbf{w}_1) = E[|\mathbf{w}_1^H \mathbf{r}(i) - \mathbf{c}_1(2i-1)|^2],$$

$$J_2(\mathbf{w}_2) = E[|\mathbf{w}_2^H \mathbf{r}(i) - \mathbf{c}_1(2i)|^2]$$

The MMSE receiver is gained by minimization problem in which is given by

$$J[\mathbf{w}_{o,1}, \mathbf{w}_{o,2}] = arg \underbrace{\min}_{\mathbf{w}_1, \mathbf{w}_2} J(\mathbf{w}_1, \mathbf{w}_2)$$

$$= \{\underbrace{\min}_{\mathbf{w}_1} J_1(\mathbf{w}_1) + \underbrace{\min}_{\mathbf{w}_2} J_2(\mathbf{w}_2)\} \quad (11)$$

which is given by

$$\mathbf{w}_{o,1} = \begin{bmatrix} \mathbf{w}_{1,1} \\ \mathbf{w}_{1,2} \end{bmatrix}, \mathbf{w}_{o,2} = \begin{bmatrix} \mathbf{w}_{2,3} \\ \mathbf{w}_{1,4} \end{bmatrix} \quad (12)$$

This cost function is further improved in [12]. A relationship is derived between $\mathbf{w}_{o,1}$ and $\mathbf{w}_{o,2}$. This was

$$\mathbf{w}_{1,2} = \mathbf{w}_{2,3}^* \text{and} \mathbf{w}_{1,4} = -\mathbf{w}_{1,1}^* \quad (13)$$

The relationship in (12) improves the convergence rate by updating only those weight vectors satisfying the condition in (13). The cost function given in (11) can be further changed as

$$J_N = J_{N1}(\mathbf{w}_d, \mathbf{w}_e) + J_{N2}(\mathbf{w}_d, \mathbf{w}_e) \quad (14)$$

where

$$J_{N1}(\mathbf{w}_d, \mathbf{w}_e) = E[|\mathbf{w}_d^H \mathbf{r}(2i-1) + \mathbf{w}_e^T \mathbf{r}^*(2i) - \mathbf{c}_1(2i-1)|^2],$$

$$J_{N2}(\mathbf{w}_d, \mathbf{w}_e) = E[|\mathbf{w}_e^H \mathbf{r}(2i-1) + \mathbf{w}_d^T \mathbf{r}^*(2i) - \mathbf{c}_1(2i)|^2]$$

The cost function given in (14) is updated using Least Mean Square (LMS) algorithm.

5. RESULTS

We implemented uplink MC-CDMA system with $M = 32$ subcarriers. The number of subcarriers is equal to spreading code length. The spreading code real and imaginary parts are selected from $1/\sqrt{2}$ and $-1/\sqrt{2}$ independently at random. We implemented Rayleigh fading using three paths for two variations: flat fading channel (FFC) and selective fading channel (SFC). We fix the channel coefficients along spreading codes in all cycles. The figure 3 to 6 represents the simulations of SLT-STBC-MC-CDMA system for Flat Fading channel (FFC) with different Doppler shifts. While, the figure 7 to 8 represents the simulations of SLT-STBC-MC-CDMA for Selective Fading Channel (SFC) with different Doppler shifts.

The figure 3 shows SNR Vs BER for flat fading channel (FFC) at Doppler shift of 5 Hz. The top curve represents FFT-STBC-MC-CDMA system. While, the second curve represent SLT-STBC-MC-CDMA system. It is observed that the performance of SLT-STBC-MC-CDMA system gives low bit error rate for low SNR as well as high SNR. The BER of SLT-STBC-MC-CDMA system falls below 10^{-3} at high SNR. While, the BER of FFT-STBC-MC-CDMA system falls up to 10^{-2} approximately at high SNR. Therefore, it can be said that SLT-STBC-MC-CDMA system gives attractive BER for all SNR at Doppler shift of 5 Hz.

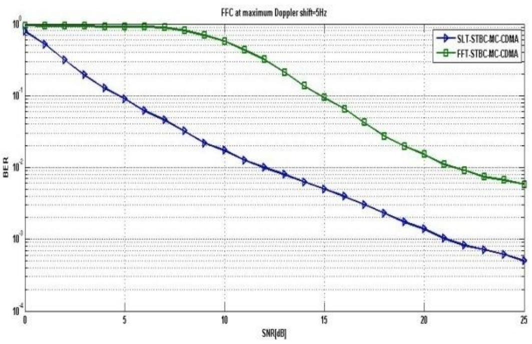

Fig. 3. Signal to Noise Ratio (SNR) Vs Bit Error Rate (BER) for Flat Fading Channel (FFC) with Doppler Shift = 5Hz

The figure 4 shows SNR Vs BER for flat fading channel (FFC) at Doppler shift of 500 Hz. The top curve represents FFT-STBC-MC-CDMA system. While, the second curve represent SLT-STBC-MC-CDMA system. It is observed that the performance of SLT-STBC-MC-CDMA system gives low bit error rate up to medium SNR in comparison to FFT-STBC-MC-CDMA system. It is further noticed that it gives steady BER of nearly 10^{-3} at SNR = 21 dB and above. Therefore, it can be said that SLT-STBC-MC-CDMA system gives attractive BER for all SNR at Doppler shift of 500 Hz as well.

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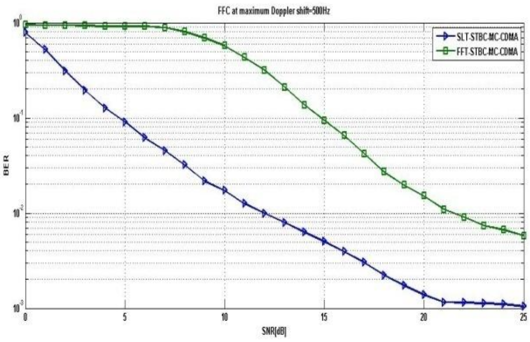

Fig. 4. Signal to Noise Ratio (SNR) Vs Bit Error Rate (BER) for Flat Fading Channel (FFC) with Doppler Shift = 500Hz.

The figure 5 shows SNR Vs BER for flat fading channel (FFC) at Doppler shift of 900 Hz. The top curve represents FFT-STBC-MC-CDMA system. While, the second curve represent SLT-STBC-MC-CDMA system. It is observed that the performance of SLT-STBC-MC-CDMA system also gives low bit error rate up to medium SNR in comparison to FFT-STBC-MC-CDMA system. It is further noticed that it gives steady BER of nearly 10^{-3}at SNR = 19 dB and above. Therefore, it can be said that SLT-STBC-MC-CDMA system gives attractive BER with respect to FFT-STBC-MC-CDMA system for all SNR at Doppler shift of 900 Hz as well.

The figure 6 shows SNR Vs BER for selective fading channel (SFC) at Doppler shift of 5Hz. The top curve represents FFT-STBC-MC-CDMA system. While, the second curve represent SLT-STBC-MC-CDMA system. It is observed that the performance of SLT-STBC-MC-CDMA system also gives low bit error rate up to medium SNR in comparison to FFT-STBC-MC-CDMA system. But, it performance badly degrades in comparison to FFT-STBC-MC-CDMA at SNR = 24dB. Therefore, it can be said that SLT-STBC-MC-CDMA system gives attractive BER in SFC with respect to FFT-STBC-MC-CDMA system up to medium SNR at Doppler shift of 5Hz. However, FFT-STBC-MC-CDMA system gives attractive BER at high SNR. Further, SLT-STBC-MC-CDMA system approaches a BER of $10^{-3.5}$ at high SNR.

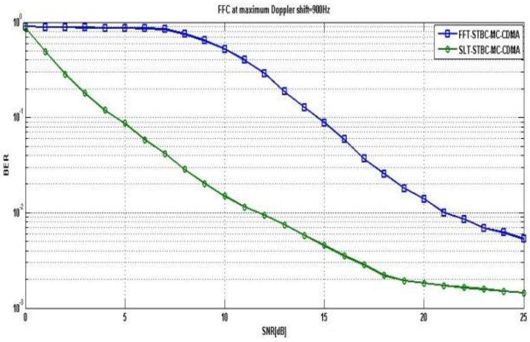

Fig. 5.Signal to Noise Ratio (SNR) Vs Bit Error Rate (BER) for Flat Fading Channel (FFC) with Doppler Shift = 900Hz.

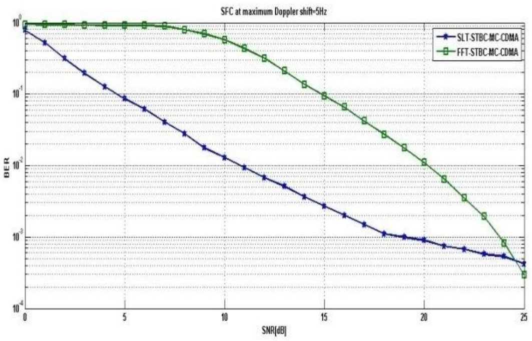

Fig. 6.Signal to Noise Ratio (SNR) Vs Bit Error Rate (BER) for Selective Fading Channel (SFC) with Doppler Shift = 5Hz.

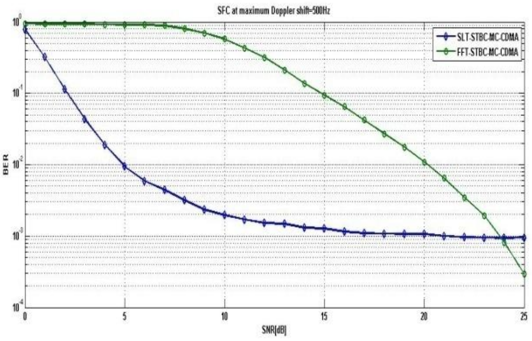

Fig. 7. Signal to Noise Ratio (SNR) Vs Bit Error Rate (BER) for Selective Fading Channel (SFC) with Doppler Shift = 500Hz.

The figure 7 shows SNR Vs BER for selective fading channel (SFC) at Doppler shift of 500Hz. The top curve represents FFT-STBC-MC-CDMA system. While, the second curve represent SLT-STBC-MC-CDMA system. It is observed that the performance of SLT-STBC-MC-CDMA system also gives low bit error rate up to medium SNR in comparison to FFT-STBC-MC-CDMA system. But, it performance badly degrades in comparison to FFT-STBC-MC-CDMA at SNR = 24dB and above. Therefore, it can be said that SLT-STBC-MC-CDMA system gives attractive BER in SFC with respect to FFT-STBC-MC-CDMA system up to medium SNR at Doppler shift of 500Hz. However, FFT-STBC-MC-CDMA system gives attractive BER at high SNR. Further, SLT-STBC-MC-CDMA system approaches a BER of 10^{-3} at high SNR.

The figure 8 shows SNR Vs BER for selective fading channel (SFC) at Doppler shift of 500Hz. The top curve represents FFT-STBC-MC-CDMA system. While, the second curve represent SLT-STBC-MC-CDMA system. It is observed that the performance of SLT-STBC-MC-CDMA system also gives low bit error rate up to medium SNR in comparison to FFT-STBC-MC-CDMA system. But, it performance badly degrades in comparison to FFT-STBC-MC-CDMA at high SNR. The SLT-STBC-MC-CDMA system gives steady BER at SNR = 18dB and above. Therefore, it can be said that SLT-STBC-MC-CDMA system gives attractive BER in SFC with respect to FFT-STBC-MC-CDMA system up to medium SNR at Doppler shift of 500Hz. However, FFT-STBC-MC-CDMA system gives attractive BER at high SNR. Further, SLT-

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STBC-MC-CDMA system approaches a BER of $10^{-2.9}$ approximately at high SNR.

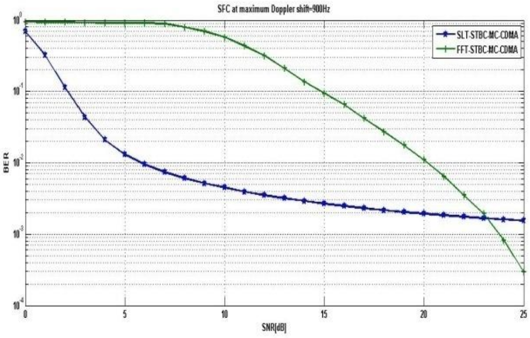

Fig. 8.Signal to Noise Ratio (SNR) Vs Bit Error Rate (BER) for Selective Fading Channel (SFC) with Doppler Shift = 900Hz.

6. CONCLUSION

The proposed Slantlet Transform based Space Time Block Coded Multi Carrier Code Division Multiple Access (SLT-STBC-MC-CDMA) system in this paper. This system is analysed for flat fading channel (FFC) and selective fading channel (SFC) at different Doppler shift. In FFC, SLT-STBC-MC-CDMA gives attractive BER rate slowly moving objects as well as fast moving objects for all SNR. While in SFC, SLT-STBC-MC-CDMA gives attractive BER rate for slowly moving objects up to medium SNR. Further it is to be added that as there are no cyclic prefix in SLT, it saves the bandwidth. This saving in bandwidth increases the data rate as well.

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AUTHOR PROFILES

1. **Muhammad Umair** received his MS (Electronic Engineering) degree from IIU, Islamabad, Pakistan, in 2009. He is PhD scholar at ISRA University, Islamabad. His research interests include Digital signal processing, Space time coding and Digital Communication.

2. **Muhammad Adnan Khan** received his MS (Electronic Engineering) degree from IIU, Islamabad, Pakistan, in 2010. He is PhD scholar at ISRA University, Islamabad. His research interests include receiver optimization, Digital signal processing, Space time coding and Digital communication.

3. **Muhammad AamerSaleem Choudhry** did his PhD in Electronic Engineering, MS in Information Technology, and M.Sc. in Electronics in 2007, 2002, and 1998 respectively. He has a number of publications in the field of communication and signal processing. He is in teaching and research field for the last fifteen years. Currently he is the Departmental Head in the University of Lahore, Islamabad.