

STBC-OFDM System under Rayleigh Fading Channel with Known and Unknown CSI at the Transmitter

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ABSTRACT: Wireless communications have quickly become part of everyday life. They have wide spread and needed every time and everywhere for use with variety of applications and services One of the most important issues in wireless communication is the multi-path fading, and this varies from one region to another depending on its terrain type. The transmitted signal in this case suffers from (reflection, diffraction and scattering) that reduces its power, changes its phase and arrives to the receiver as multiple replica of the signal with different time delays and amplitudes which attenuate the original received signal. OFDM-multiplexes several orthogonal parallel data rate in a way to overcome fading impairment and to increase system spectral efficiency from the other hand MIMO provides a significant capacity gain over conventional single antenna system and improves system reliability. Combining MIMO and OFDM provide both performance and capacity improvement. In this paper, an investigation of STBC for MIMO-OFDM system simulation using MATLAB program have been achieved to analyse its performance with known and unknown Channel State Information (CSI). The Rayleigh fading channel with Stanford University Interim model (SUI-3) was used. Orthogonal Space-Time Block Codes (OSTBC) was used to enhance spatial diversity gain and the overall system performance for unknown (CSI) at the transmitter. Singular Value Decomposition (SVD) was employed to precede the input data stream when (CSI) is known at the transmitter.

KEYWORDS: OFDM, CSI, OSTBC, SVD, STBC-OFDM, MIMO-OFDM.

I. INTRODUCTION

In practice, wireless communications channels are frequency selective or time varying mainly for mobile applications and broadband. To address these challenges, a promising combination namely, MIMO-OFDM has been exploited. Because OFDM is a multi-carrier transmission technique, it can reduce the effect of frequency selective channel by dividing the available spectrum into many carriers, each modulated by a low-rate data stream. STBC-OFDM coding is a popular combination of MIMO and OFDM. It distributes symbols along different transmit antennas and time slots of OFDM blocks to enhance the system Performance. Hence, the STBC-OFDM system most promising system configurations adopted for 4th generation mobile systems [1]. The simple, linear decoding, low complexity receiver are the main advantages that have made them a popular choice for future wireless communications

This work presented improvement of the BER performance by experiment the concepts of transmitter and receiver diversity techniques through increasing the number of antennas. Rayleigh fading wireless channel was considered. It has higher value BER than AWGN reference channel. Due to this the performance over the Rayleigh fading wireless channel is significantly poor, even at high SNR. The main objective of diversity technique is to reduce the value of the BER as SNR increases in the Rayleigh fading environment.

The exploiting of diversity at the transmitter side in the downlink is important. To implement this phenomenon a transmission technique called Space Time Block Coding (STBC) is used: In this technique, CSI is available at the receiver side only, fully diversity gain was achieved but without antenna array gain. Due to the use of more than two antennas at the transmitter the code rate will be less than one. For this reason an Alamouti transmit diversity is used where code rate of one may achieved in (2X2) antenna system. The paper is outlined as follow: In section 2, system

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model of STBC-OFDM is described. In section 3, comparison between two states, if the transmitter has knowledge of the channel state information or not is described. Then the paper ends with the Conclusion.

II. SYSTEM MODEL

1- OFDM

OFDM is the developed technique of Frequency Division Multiplexing (FDM). Orthogonality is a feature that allows multiple signals to be perfectly transmitted over a specific channel and detected without inter carrier interference (ICI). Figure 1 below shows the block diagram of OFDM

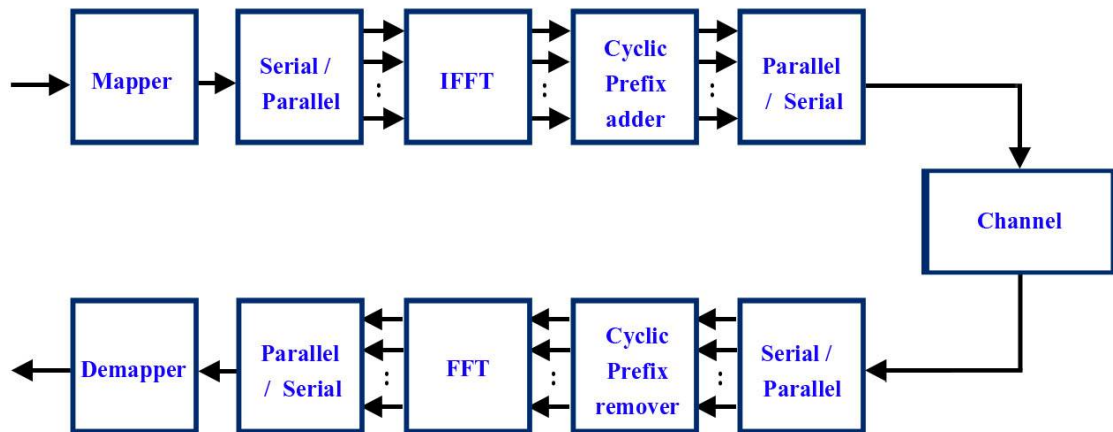


Fig.1 OFDM Basic Block Diagram (Transmitter/Receiver)

An important factor in the data transmission is the channel estimation, its process based on pilots' insertion into some of the sub-carrier frequencies for each OFDM symbol, in this paper the improved technique to MMSE that use Discrete Furrier Transform of Minimum Mean Square Error (DFT-MMSE) estimation is used. It has been introduced to improve the performance of Minimum Mean Square Error (MMSE) estimation MMSE by eliminating the effect of noise outside the maximum channel delay. The noisy channel estimation (which is in frequency domain) is transformed to time domain by IDFT with number of N, then it transformed back to frequency domain by DFT after a suitable process in order to reduce noise effects as shown in figure 2 [2,3].

Let $\tilde{H}(k)$ denotes the channel gain estimated at the k th subcarrier, obtained by MMSE channel estimation method. By taking the IDFT of the estimated channel response $\{\tilde{H}(k)\}_{k=0}^{N-1}$

$$\text{IDFT}\{\tilde{H}(k)\} = \mathbf{h}(N) + \mathbf{w}(N) \cong \tilde{\mathbf{h}}(n) \quad n=0,1,\dots,N-1 \quad (1)$$

Where $w(n)$ denotes the noise component in the time domain. By ignoring the coefficients $\{\tilde{h}(n)\}$ that contain the noise only, define the coefficients for the maximum channel delay P as

$$\text{III. } \tilde{\mathbf{h}}_{DFT}(n) = \begin{cases} \mathbf{h}(n) + \mathbf{w}(n), & n = 0, 1, \dots, P-1 \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

Then transform the remaining P elements back to frequency domain as [2]

$$\tilde{\mathbf{H}}_{DFT}(k) = \text{DFT}\{\tilde{\mathbf{h}}_{DFT}(n)\} \quad (3)$$

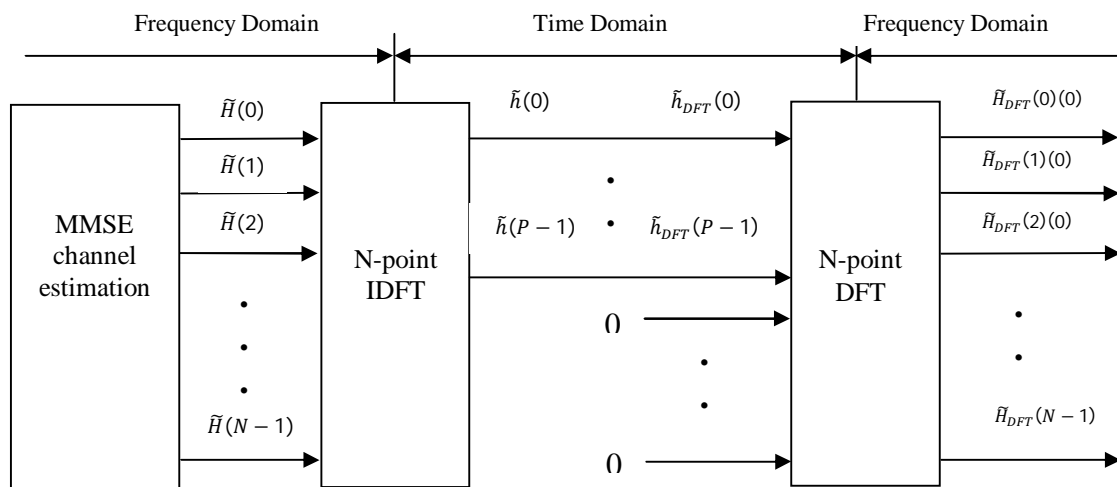


Fig. 2 DFT-MMSE channel estimation [2]

2- MIMO SYSTEM

MIMO technology can be defined as the use of multiple antennas at transmitter and receiver sides in wireless system. It is widely accepted technology that makes the received signal to be robust against fading channel. MIMO becomes the primary tool that increases capacity significantly in high SNR region. MIMO is one of diversity technique types that can be applied in time domain or frequency domain or it may be mixed with space diversity as shown in figure 3. While Time diversity alone requires multiple of time interval (T) to ensure data to be received correctly at the receiver which limits system capacity and decreases data rate, from the other hand frequency diversity alone reserves large amount of bandwidth (BW) due to repetition in frequency domain which conflicts with allowable frequency resources; space diversity overcomes these disadvantages and replaces time and frequency wastage by some of complexity in implementation and design.

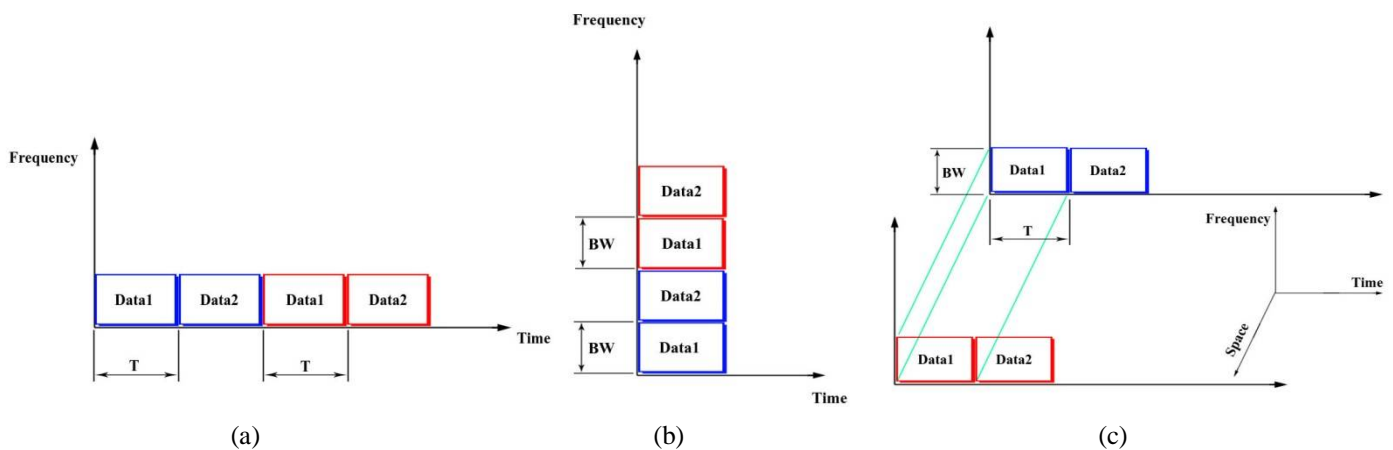


Fig. 3 diversity techniques (a) Time Diversity (b) Frequency Diversity (c) Space Diversity

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Figure 4 shows the MIMO system, the relations between transmitted and received signals are:

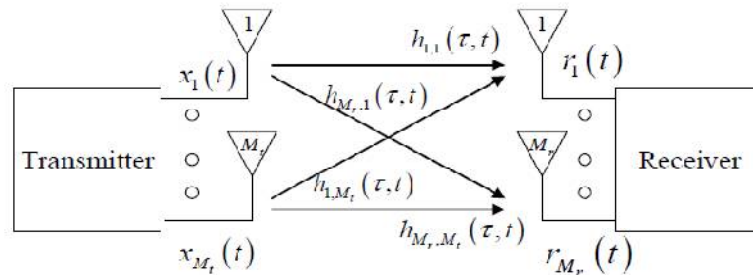


Figure (4) MIMO System

$$\begin{aligned}
 r_1(t) &= x_1(t) * h_{1,1}(\tau, t) + x_2(t) * h_{1,2}(\tau, t) + \dots + x_{M_t}(t) * h_{1,M_t}(\tau, t) \\
 r_2(t) &= x_1(t) * h_{2,1}(\tau, t) + x_2(t) * h_{2,2}(\tau, t) + \dots + x_{M_t}(t) * h_{2,M_t}(\tau, t) \\
 &\vdots \\
 r_{M_r}(t) &= x_1(t) * h_{M_r,1}(\tau, t) + x_2(t) * h_{M_r,2}(\tau, t) + \dots + x_{M_t}(t) * h_{M_r,M_t}(\tau, t)
 \end{aligned}
 \tag{4}$$

Then the channel matrix $H(\tau, t)$ can be represented as

$$H(\tau, t) = \begin{bmatrix}
 h_{1,1}(\tau, t) & h_{1,2}(\tau, t) & \dots & h_{1,M_t}(\tau, t) \\
 h_{2,1}(\tau, t) & h_{2,2}(\tau, t) & \dots & h_{2,M_t}(\tau, t) \\
 \vdots & \vdots & \ddots & \vdots \\
 h_{M_r,1}(\tau, t) & h_{M_r,2}(\tau, t) & \dots & h_{M_r,M_t}(\tau, t)
 \end{bmatrix}
 \tag{5}$$

Equations (4) and (5) considered as a generalized equations for any type of channel. There are two major types of channel; flat fade and frequency selective channel. Practically MIMO works better under flat fading conditions, adding OFDM technique to MIMO system will improve the quality of working under frequency selective channel after converting it to a number of flat fading channels. Therefore, the indices of delay τ and time t of the channel are dropped and the channel is denoted as h_i , $i=1,2,\dots,n$, representing single tap impulse responses and this is known as quasi-static channel model where it does not changed during the channel block but it could be changed from block to block [4].

3- Space-Time Block Codes (STBC)

The family of time-space processing methods associated with the point-to-point related smart antenna applications through sending information on multiple transmit antennas (in space) over multiple of sequential data transmissions (in time). Therefore it is said to transmit information (codes) in space and time [5].

Usually, wireless channel suffers from fading due to constructive and destructive addition of multi-paths in the propagation media. In Rayleigh channel, it is difficult for the receiver to reliably determine the transmitted signal

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unless some less attenuated replica of the signal is provided to the receiver. STBC technique used in MIMO systems aim to either achieve higher performance through spatial diversity or higher data rate through spatial multiplexing. The target of the space time block coding is to achieve maximum diversity gain which defined as the product of transmitting and receiving antenna numbers in MIMO systems. Alamouti is one of popular designs of Orthogonal Space-Time Block Coding (OSTBC) that provides full data rate and full diversity in addition to a simple decoding, which is a way of distributing the transmitted data among the transmitted antennas in a derivative manner to get orthogonality between transmitted signals; it sends a block of data stream in multiple parts out of multiple antennas that interleaved with conjugated version of the same data. Use of STBC for MIMO systems has generated a lot of interesting to increase spectral efficiency and improved BER performance in the wireless systems. Therefore, a lot of work had been carried out on STBC-MIMO system techniques especially through orthogonal designs suggested by Alamouti which remain most popular [6].

The Alamouti scheme is the first space-time block code which provides full transmit diversity for the system with transmit antennas of two, its encoding matrix form is

$$X_{(2)} = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} \quad (8)$$

The Alamouti transmission technique is as follows: two different data symbols x_1 and x_2 are transmitted simultaneously from antennas 1 and 2, respectively, during the first symbol period, following which symbols $-x_2^*$ and x_1^* are launched from antennas 1 and 2, respectively. It is clear that the encoding is performed in both time domain (two transmission intervals) and space domain (across two transmit antennas). The two rows and columns of X are orthogonal to each other and the code matrix (3.4) is orthogonal:

$$XX^H = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} \begin{bmatrix} x_1^* & x_2 \\ -x_2 & x_1 \end{bmatrix} = \begin{bmatrix} |x_1|^2 + |x_2|^2 & 0 \\ 0 & |x_1|^2 + |x_2|^2 \end{bmatrix} = (|x_1|^2 + |x_2|^2)I_2 \quad (9)$$

Where I_2 is a (2×2) identity matrix. This property enables the receiver to detect x_1 and x_2 by a simple linear signal processing operation [7].

At the receiver side, the received signals in two adjacent time slots (t_1 and t_2) are [7]

$$\begin{aligned} r(t_1) &= r_1 = (h_1 x_1 + h_2 x_2) + w_1 \quad (10) \\ r(t_2) &= r_2 = (-h_1 x_2^* + h_2 x_1^*) + w_2 \end{aligned} \quad (11)$$

By compensating the equations (10) and (11), results the following matrix:

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} + \begin{bmatrix} w_1 \\ w_2 \end{bmatrix} \quad (12)$$

Multiplying both sides of equation (12) by the transpose conjugate of input data matrix gives

$$\begin{bmatrix} x_1^* & -x_2 \\ x_2^* & x_1 \end{bmatrix} \begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = (|x_1|^2 + |x_2|^2) \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} + \begin{bmatrix} x_1^* & -x_2 \\ x_2^* & x_1 \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \end{bmatrix} \quad (13)$$

Or can be rewritten as

$$\begin{bmatrix} \tilde{r}_1 \\ \tilde{r}_2 \end{bmatrix} = (|x_1|^2 + |x_2|^2) \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} + \begin{bmatrix} \tilde{w}_1 \\ \tilde{w}_2 \end{bmatrix} \quad (14)$$

This leads to

$$\tilde{r}_1 = (|x_1|^2 + |x_2|^2) h_1 + \tilde{w}_1 \quad (15)$$

$$\tilde{r}_2 = (|x_1|^2 + |x_2|^2) h_2 + \tilde{w}_2 \quad (16)$$

It can be concluded from equations (15) and (16) that the received signal can depend on one channel response at a time i.e. Alamouti deals with different channels as parallel and independent. Returning to equations (10) and (11), the following matrix can be obtained:

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$$\begin{bmatrix} r_1 \\ r_2^* \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} w_1 \\ w_2^* \end{bmatrix} \quad (17)$$

And after achieving channel estimation at the receiver combiner for each branch, the result estimated signals are [7]:

$$\tilde{x}_1 = h_1^* r_1 + h_2 r_2^* \quad (18)$$

$$\tilde{x}_2 = h_2^* r_1 - h_1 r_2^* \quad (19)$$

Alamouti scheme was designed for 2 transmit antennas and generalized to more than 2 antennas. Increasing the number of antennas will improve the system performance, full rate can only achieved with two transmit antennas system when the data are of complex form, while these are not exist for higher order case. A generalized method to design orthogonal codes for any number of antennas was introduced [], the coding matrices for 3 and 4 antennas are as shown

$$X_{(3)} = \begin{bmatrix} x_1 & -x_2 & -x_3 & -x_4 & x_1^* & -x_2^* & -x_3^* & -x_4^* \\ x_2 & x_1 & x_4 & -x_3 & x_2^* & x_1^* & x_4^* & -x_3^* \\ x_3 & -x_4 & x_1 & x_2 & x_3^* & -x_4^* & x_1^* & x_2^* \end{bmatrix} \quad (20)$$

$$X_{(4)} = \begin{bmatrix} x_1 & -x_2 & -x_3 & -x_4 & x_1^* & -x_2^* & -x_3^* & -x_4^* \\ x_2 & x_1 & x_4 & -x_3 & x_2^* & x_1^* & x_4^* & -x_3^* \\ x_3 & -x_4 & x_1 & x_2 & x_3^* & -x_4^* & x_1^* & x_2^* \\ x_4 & x_3 & -x_2 & x_1 & x_4^* & x_3^* & -x_2^* & x_1^* \end{bmatrix} \quad (21)$$

4- Singular Value Decomposition (SVD)

Alamouti Scheme considers that CSI is unknown at transmitter side and completely known at the receiver, and puts the matrix form to improve performance upon such case. If CSI is considered to be known in such way at transmitter side, a method called singular value decomposition (SVD) is used to obtain more improvement upon system. Figure (5) shows the steps of SVD theorem on signal

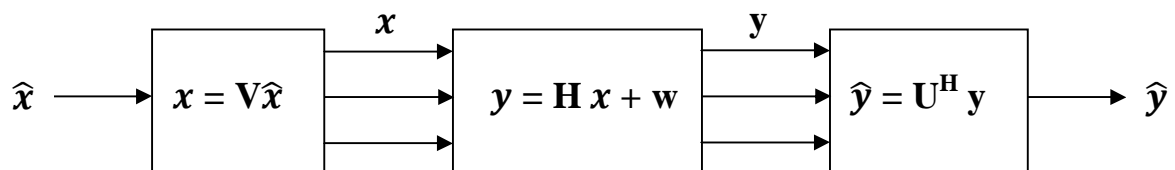


Fig. 5 Steps of SVD

SVD is a mathematical application that creates an alternate structure of the multiple antennas signal. The H matrix channel can be formed as

$$H = U \Sigma V^H \quad (22)$$

Where U and V are unitary matrices ($U^H U = I$, $V^H V = I$),

Σ is $M \times M$ diagonal matrix of singular values of H matrix.

$$\begin{aligned} \hat{y} &= U^H \cdot y = U^H (H x + w) = U^H (U \Sigma V^H x + w) = U^H (U \Sigma V^H V \hat{x} + w) = U^H U \Sigma V^H V \hat{x} + U^H w \\ &= \Sigma \hat{x} + U^H w \end{aligned}$$

This results in equation below

$$\hat{y} = \Sigma \hat{x} + \hat{w} \quad (23)$$

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The output signal is in form of a pre-coded input signal \hat{x} times the singular value matrix, Σ . Note that the multiplication of noise w , by the unitary matrix UH which gives \hat{w} does not change the noise distribution [8].

IV. SIMULATION MODELLING AND RESULTS

Simulation modelling and results are obtained through sending random data within specific Rayleigh channel in different methods of transmitting and receiving techniques, then calculating BER obtained at the output of receiver chain. Standard SUI-3 channel modelling is used to simulate Rayleigh channel for certain values of number of paths, attenuation, path delay and maximum Doppler shift. BER calculations are repeated for different values of SNR and check the level of improvement for each way of the simulated methods.

V. RESULTS AND DISCUSSION

This section contains different tests, (4X4) MIMO-OFDM comparison with spatial multiplexing technique first with normal way of unknown CSI at transmitter side through the use of Alamouti scheme, and second with SVD method that depends on the knowledge of channel response at transmitter side. Figures (6 and 7) show BER computation of MIMO-OFDM (4X4) with spatial multiplexing for known CSI at receiver only and known CSI at transmitter using SVD method.

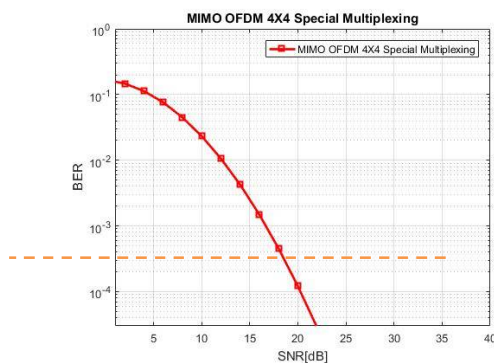


Fig.6 MIMO-OFDM (4X4) spatial multiplexing

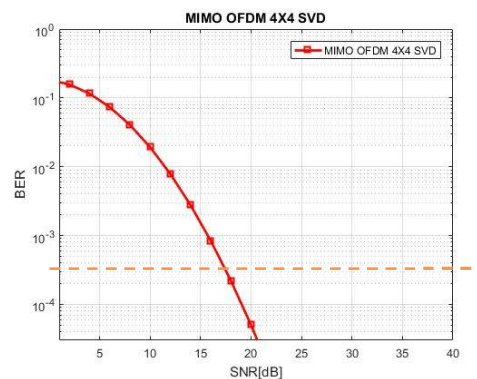


Fig. 7 MIMO-OFDM (4X4) spatial multiplexing with SVD method

VI. CONCLUSION

When comparing figures (6) and (7), for spatial multiplexing of MIMO-OFDM (4X4), the use of SVD method that requires CSI knowledge at transmitter side improves BER performance about (1dB) compared with the normal way of sending data with unknown CSI at transmitter side.

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