Performance Comparison of Various Detection Methods for STBC based OFDM System for Time Varying Multipath Fading channel

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***Abstract*— The performance analysis of Alamouti space time block code (STBC) based orthogonal frequency division multiplexing (OFDM) is often analyzed on the assumption that the channel is constant over Alamouti code period (two consecutive OFDM symbol block). But when the channel is fast fading, this assumption does not hold good and causes co-channel interference (CCI). Hence, the simple Alamouti detection method is not sufficient to recover the original transmitted signal from the mixed transmitted signals at the receiver side. In this paper, we investigate several detection methods for cancelling the effect of CCI which includes SIC, ZF and DF. Finally, the performances of the above detection method are compared on the basis of symbol error rate (SER) for different mobile speed.**

***Key Words* — STBC, OFDM, CCI, DECODER**

I. INTRODUCTION

Now a days, all most all wireless communication system is focusing on reliability and spectral efficiency [1]-[2]. The link reliability is solved by STBC which is proposed by Alamouti [3]. The STBC technique is expanded to arbitrary number of transmit and receive antenna by [4]-[5]. Originally, the STBC technique is applied to flat fading channel. But in practical scenario, the channel is frequency selective as well as time selective rather than flat fading. The frequency selective problem can be solved by applying OFDM technique to the STBC system as OFDM converts the frequency selective fading channel into many narrow parallel flat fading channels [6]. However, in time varying fast fading channel the Alamouti STBC-OFDM system undergoes two types of interfering namely inter-carrier interference (ICI) and CCI [7]-[10]. The ICI is occurred due to the loss of orthogonality among the subcarrier within the OFDM block. The CCI is occurred due to the variation of channel frequency response (CFR) over Alamouti code period. Due to the CCI effect, the two consecutive transmitted OFDM symbol blocks are coupled with each other at the receiver side. Both the ICI and CCI cause significant performance degradation in time varying fast fading channel. However the power of CCI is proved to be 7 - 8 dB greater than the power of ICI regardless of the channel variation [10]. Hence, we only consider the CCI effect on the Alamouti coded OFDM system.

In the previous literature, various detection methods have been addressed for cancelling the effect of CCI. In [11], a diagonalized maximum likelihood detector (DMLD) is proposed to remove the CCI. But the DMLD method is more computational complexity. Hence, a similar performance with low computational complexity zero forcing (ZF) detector is proposed in [12]. A successive interference cancellation (SIC) method [10] is proposed. The SIC method has a low computational cost but its performance is not accurate enough due to the error propagation problem. The decision feedback (DF) method is originally proposed in [13]. Then it is extended for STBC/SFBC OFDM system in [9]. The performance of DF detector is better than the Alamouti, SIC and ZF detector but with a little bit higher computational cost. In this paper, we have studied the above detection methods for cancellation the effect of CCI in STBC-OFDM system over fast fading multipath fading channel.

The rest of the paper is organized as follows. In section II, the system model for the STBC based OFDM system along with the channel model is discussed. The different detection techniques are presented in Section III. In section IV, the performance of these detection methods are compared on the basis of SER. Finally, section V concludes the paper.

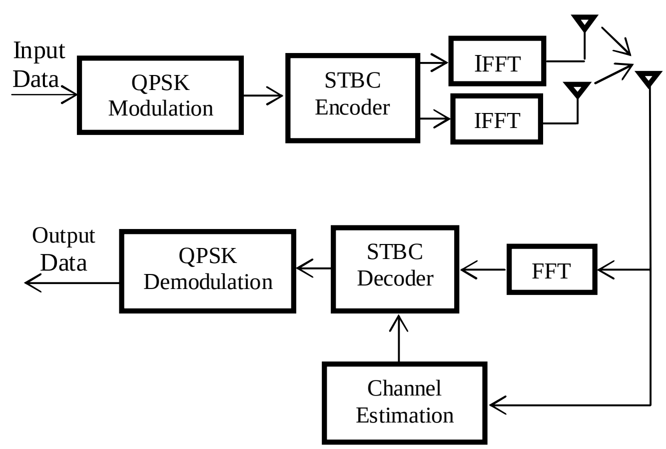

Fig.1 Block diagram of an STBC-OFDM system model

II. SYSTEM MODEL

In this section, an STBC based OFDM system with two transmit antenna and one receive antenna is described along with the exponential power delay profile with jakes sum of sinusoidal (SOS) channel model as time varying multipath Rayleigh fading channel.

A. STBC Based OFDM System Model

The system model for STBC-OFDM with two transmit antenna and one receive antenna is shown in the Fig1. At the transmitter side, a random data sequence is generated and modulated according to any specific modulation scheme such as BPSK, QPSK or 16QAM. Then the output modulated data are passed through the STBC encoder. The STBC encoder converts the single input modulated information data into two parallel encoded output data according to Alamouti STBC scheme [3]. The Alamouti STBC scheme is described as follows. At the first time instant $X_1(k)$ and $X_2(k)$ are transmitted from the transmit antenna 1 and 2 respectively. In the second time instant $-X_2^*(k)$ and $X_1^*(k)$ are transmitted from antenna 1 and 2 respectively. Hence, the output of the STBC encoder can be written in matrix form and is given in bellow

$$X(k) = \begin{bmatrix} X_1(k) & X_2(k) \\ -X_2^*(k) & X_1^*(k) \end{bmatrix} \quad (1)$$

where $k = 0,1,2,\ldots\ldots N-1$

$X_1(k)$ is the k^{th} subcarrier for the transmitting antenna 1 before the IFFT operation and N is the number of subcarrier in a single OFDM symbol block.

Then, the encoded output signal is passed through the serial to parallel converter(S/P) and finally reached at the Inverse Fast Fourier Transformation (IFFT) block. Finally, the resulting signals are transmitted from the antennas after insertion of the cyclic prefix (CP) which is assumed to be larger than delay spread of the multipath channel in order to avoid inter symbol interferences (ISI).At the receiver side, at first the CP is removed and then the received signal is processed by a Fast Fourier Transformation (FFT). The FFT output of the received signal after the removal of CP can be written in the matrix form and is given here

$$Y(k) = \begin{bmatrix} Y_t(k) \\ Y^*_{t+T}(k) \end{bmatrix} = \begin{bmatrix} H_{1,t}(k) & H_{2,t}(k) \\ H^*_{2,t+T}(k) & -H^*_{1,t+T}(k) \end{bmatrix} \begin{bmatrix} X_1(k) \\ X_2(k) \end{bmatrix} + \begin{bmatrix} Z_t(k) \\ Z^*_{t+T}(k) \end{bmatrix} = HX + Z \quad (2)$$

where $H_{1,t}(k)$ and $H_{2,t}(k)$ are the CFR for the first and second transmit antenna at the first time instant respectively. $Z_t(k)$ is the circularly complex zero mean additive white Gaussian noise after the FFT operation.

It is to be noted that the channel is taken to be ideal where it is assumed that the perfect channel knowledge is known at the receiver side. According to Alamouti scheme, the channels is considered to be static over two consecutive OFDM symbol block, i.e., $H_{1,t} = H_{1,t+T}$ and $H_{2,t} = H_{2,t+T}$. The STBC decoding operation is performed by multiplying H^H on both the side of the equation (2), the original transmitted signal can be recovered after taking the hard decision of the decoded signal and can be written as

$$\hat{X}(k) = Q\left(\frac{\tilde{X}(k)}{\Phi(k)}\right) \quad (3)$$

where $\tilde{X} = H^H(k)Y(k)$

$$\Phi(k) = \left|H_{1,t}(k)\right|^2 + \left|H_{2,t+T}(k)\right|^2 = \left|H_{1,t}(k)\right|^2 + \left|H_{2,t+T}(k)\right|^2$$

where

$\tilde{X}$ is the decoded signal and Q denotes the hard decesion function.

Hence, the two estimated signals $\hat{X}(k)$ are decoupled from each other at the receiver side. However, in the fast fading channel, the channels are not same for two different time slots. Hence, $H^H H$ is no longer a orthogonal matrix and is given by

$$G = H^H H = \begin{bmatrix} \alpha_1(k) & \beta(k) \\ \beta^*(k) & \alpha_2(k) \end{bmatrix} \quad (4)$$

where $\alpha_1(k) = \left|H_{1,t}(k)\right|^2 + \left|H_{2,t+T}(k)\right|^2$

$$\alpha_2(k) = \left|H_{1,t+T}(k)\right|^2 + \left|H_{2,t}(k)\right|^2$$

$$\beta(k) = H^*_{1,t}(k)H_{2,t}(k) - H^*_{1,t+T}(k)H_{2,t+T}(k)$$

$\alpha_1(k), \alpha_2(k)$ are the desired diversity gain terms and $\beta(k)$, $\beta^*(k)$ are the CCI terms. By multiplying G with FFT output of the received signal Y, the detected output signal vector can be written as

$$\tilde{X} = \begin{bmatrix} \tilde{X}_1(k) \\ \tilde{X}_2(k) \end{bmatrix} = \begin{bmatrix} \alpha_1(k)X_1(k) + \beta(k)X_2(k) + Z'_t(k) \\ \beta^*(k)X_1(k) + \alpha_2(k)X_2(k) + Z'_{t+T}(k) \end{bmatrix} \quad (5)$$

$\alpha_1(k)X_1(k)$ and $\alpha_2(k)X_2(k)$ are the desired signal. $\beta(k)X_2(k)$ and $\beta^*(k)X_1(k)$ are the CCI signal which are coupled with the desired signal at the receiver side.

Hence, in order to accurately recover the original transmitted signal, these two CCI signals are to be cancelled.

B. Channel Model

In this paper, an exponential power delay profile (PDP) channel [14] is adopted for the STBC-OFDM system model. The channel is modeled as finite impulse response (FIR) with total L+1 non-zero path with zero mean and average power σ_l^2.

The channel can be expressed by

$$h_l = N(0, \frac{\sigma_l}{2}) + jN(0, \frac{\sigma_l}{2}) \tag{6}$$

where $N(0, \frac{\sigma_l}{2})$ is the zero mean with variance σ_l^2.

The power of multipath component decreases exponentially. The first path of the model is chosen to be

$$\sigma_0^2 = \frac{1-\lambda}{1-\lambda^{L+1}} \tag{7}$$

where $\lambda = e^{-\frac{T_s}{\tau_{rms}}}$

The T_s and τ_{rms} are the sampling period and root mean squared delay of the channel respectively. The energy of the l^{th} can be written as

$$\sigma_l^2 = \sigma_0^2 \lambda^l. \tag{8}$$

Furthermore, each multipath is modeled as uncorrelated Rayleigh fading channel with Jakes sum-of-sinusoidal (SOS) model [15].

III. Detection Methods for CCI cancellation

In this section, we describe different detection method namely the SIC detection method, the ZF detection method and the DF detection method in order to cancel the effect of CCI in the STBC based OFDM system for fast fading multipath channel.

A. SIC Detection Method

The successive interference cancellation method is proposed in [10]. Due to the time varying nature of channel, the two diversity gain terms are not same but the gains of the two CCI terms are equal as given in the equation (4). Hence the SIC detection method is based on this gain difference property to recover the original transmitted signal and is illustrated below.

1. $$\tilde{X}_1(k) = \alpha_1(k)X_1(k) + \beta(k)X_2(k) + Z'_t(k) \tag{9}$$

2. $$\tilde{X}_2(k) = \beta^*(k)X_1(k) + \alpha_2(k)X_2(k) + Z'_{t+T}(k) \tag{10}$$

3. *if* $\alpha_1(k) > \alpha_2(k)$

$$\begin{aligned} \hat{X}_1(k) &= Q(\tilde{X}_1(k)/\alpha_1(k)) \\ \hat{X}_2(k) &= Q((\tilde{X}_2 - \beta^*(k)\hat{X}_1(k))/\alpha_2(k)) \end{aligned} \tag{11}$$

4. *else*

$$\begin{aligned} \hat{X}_2(k) &= Q(\tilde{X}_2(k)/\alpha_2(k)) \\ \hat{X}_1(k) &= Q((\tilde{X}_1 - \beta(k)\hat{X}_2(k))/\alpha_1(k)) \end{aligned} \tag{12}$$

The SIC detection method gives better results than Alamouti method with a low computational cost, however it is not accurate enough to recover the original transmitted signal due to its error propagation problem.

B. ZF Detection Method

In the time varying fast fading channel, multiplying H^H with H does not give a orthogonal matrix as explained in the equation (4). In order to make the equation (4), an orthogonal matrix, a Ω matrix is multiplied with the H matrix [11] and is given below

$$\Omega H = \mathrm{diag}(\varphi_1, \varphi_2) \tag{13}$$

where φ_1 and φ_2 are the complex number.

After simplification of the equation (13), Ω can be written in the matrix form and is given by

$$\Omega = \begin{bmatrix} H^*_{1,t+T}(k) & H_{2,t}(k) \\ H^*_{2,t+T}(k) & -H_{1,t}(k) \end{bmatrix} \tag{14}$$

The φ_1 and φ_2 have the same value and is given by

$$\begin{aligned} \varphi &= \varphi_1 = \varphi_2 \\ &= H^*_{1,t+T}(k)\,H_{1,t}(k) + H_{2,t}(k)\,H^*_{2,t+T}(k) \end{aligned} \tag{15}$$

Substituting Ω in the place of H^H, the equation (2) becomes

$$\tilde{X} = \Omega Y = \mathrm{diag}(\varphi, \varphi)X + \Omega Z \tag{16}$$

The estimated original transmitted signal can be obtained by dividing the value of φ on both the side and then taking the hard decision

$$\hat{X}_1(k) = Q(\frac{\tilde{X}_1(k)}{\varphi(k)}) = X_1 + Z \tag{17}$$

$$\hat{X}_2(k) = Q(\frac{\tilde{X}_2(k)}{\varphi(k)}) = X_2 + Z \tag{18}$$

The ZF detection method is simple and gives better result than SIC as it simply forces the two CCI terms to zero.

C. DF Detection Method

The DF detector was proposed for STBC-OFDM system in [9]. The working principle of DF detection method is described as follows. The DF first estimated a signal and then uses this estimated signal to help make decision about the other estimated signal by assuming that the first estimated signal is correct. The algorithm of DF detection method is given below.

1. Estimate the first signal $\hat{X}_1$ using ZF detection method by using the equation (17).
2. Cancel the contribution of $\hat{X}_1$ by subtracting it from the mixed detected output signal in equation (9). Then take the hard decision to obtain the estimated signal $\hat{X}_2$. The estimated signal $\hat{X}_2$ can be written as

$$\hat{X}_2(k) = Q((\tilde{X}_2 - \beta^*(k)\hat{X}_1(k))/\alpha_2(k)) \qquad (19)$$

IV. SIMULATION RESULTS

The performance comparison of different detection methods including Alamouti, SIC, ZF and DF methods for STBC based OFDM system are carried out on the basis of SER over various mobile speeds. The total simulation parameter used for simulation is listed on the Table1.

Table1.Simulation Parameter

Parameter	Value
FFT Size	128
Number of Subcarrier	128
Number of CP	32
Data Modulation	QPSK
Carrier Frequency	5GHz
Channel BW	1MHz
Subcarrier Spacing	7.8125KHz
Channel Model	Exponential decaying PDP with each path modeled as Jakes SOS
Number of Multipath	3
RMS Delay spread	1us
Mobile speed	50/100/200 Km/h
Normalized Doppler frequency (f_dNTs)	0.03/0.059/0.12

The SER performance for Alamouti, SIC, ZF and DF detectors for mobile speed 50Km/h (normalized Doppler frequency $f_dNT_s = 0.03$) is shown in the Fig.2. The simulation result shows that Alamouti method suffers severe performance degradation due to both CCI and ICI. The performance of SIC method is better than Alamouti detection method but is not enough accurate due to error propagation problem. The ZF detector simply forces the CCI signal to zero and gives better results than SIC method. The DF detector outperforms all of the above detection methods including Alamouti, SIC and ZF methods. Fig.3 and Fig.4 show the SER performance of various detection methods for normalized Doppler frequency of 0.059 and 0.12 respectively. From the Fig.2-Fig.4, it is seen that, when, the normalized Doppler frequency increases, the SER decreases drastically. The performance of different detection methods in the descending order are given as follows: DF, ZF, SIC and Alamouti.

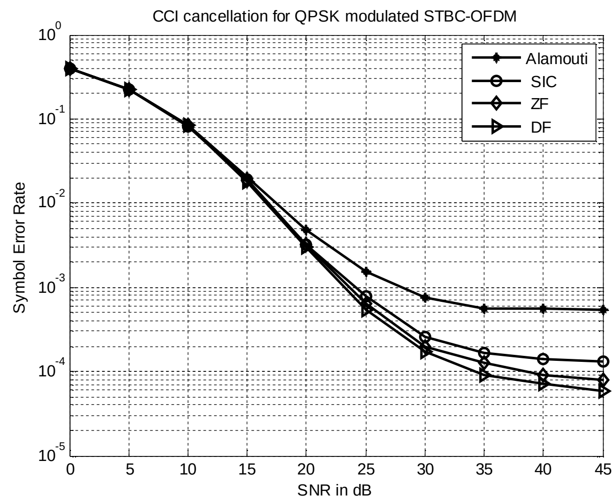

Fig.2 SER Vs SNR for different detection methods for normalized doppler frequency of 0.03

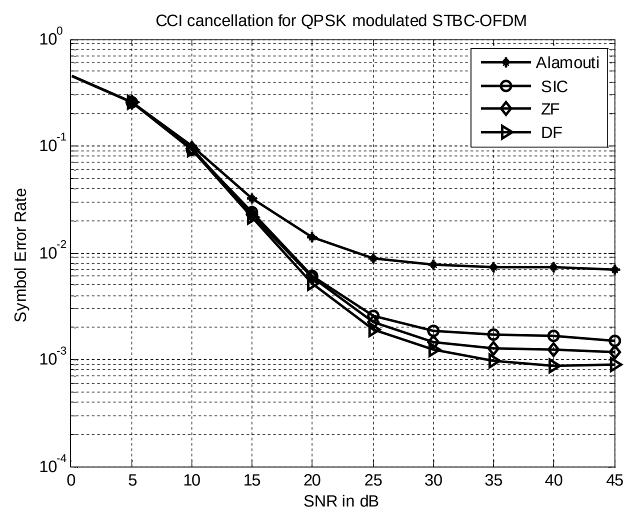

Fig.3 SER Vs SNR for different detection methods for normalized doppler frequency of 0.059

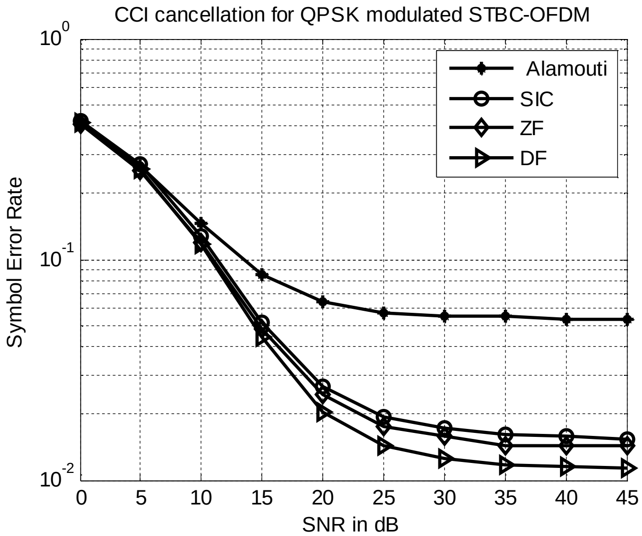

Fig.4. SER Vs SNR for different detection methods for normalized doppler frequency 0.12

V. CONLCUSION

In this paper, we have investigated different detection techniques for STBC based OFDM system including Alamouti, SIC, ZF and DF for fast fading multipath fading channel. The Alamouti detection method performs the worst due to the severe CCI and ICI effect. The SIC method gives better results than Alamouti method but suffer from error propagation problem. The ZF detection method simply forces the CCI signal to zero and hence gives better results than SIC as no error propagation is occurred. The DF detector outperforms all of the described detection techniques because it uses the first estimated signal correctly by using ZF detection method and then cancels its contribution from the mixed transmitted signal at the receiver side to estimate the other data signal. We also see that as the normalized doppler frequency increases, the SER decreases dramatically.

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