Performance analysis of Adaptive Switching Between Space-Time and Space-Frequency Block Coded OFDM Systems using ZF and MMSE techniques.

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Abstract—This paper focuses on the implementation and performance analysis of adaptive switching between STBC and SFBC OFDM systems [1].Here in this paper we proposed an adaptive transmission technique for MIMO OFDM systems using adaptive equalization algorithms (ZF,MMSE) where the channel response are unknown a priori and time variant. In this paper two selection criteria, correlation of the channel and magnitude of the interference, are proposed for transmission mode selection . In criterion I, correlation between successive OFDM symbols for STBCOFDM and correlation between neighboring subcarriers for SFBC-OFDM are compared and the mode which has higher correlation value is selected to maximize the SNR. Next, in criterion II, we choose the mode which has smaller Inter symbol Interference to reduce the performance degradation. Simulation results show that the proposed adaptive switching system shows better performance with ZF and MMSE equalizers[8].

keywords – space-time code (STC), MIMO-OFDM systems, adaptive switching, Zero forcing, Minimum mean square error.

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I. INTRODUCTION

Two popular approaches to combine the space time codes and OFDM systems are STBC-OFDM and SFBC-OFDM [2] [3]. However, since the symbol duration of OFDM symbol is significantly increased compared to that of a single carrier system, the assumption of constant channel response during the transmission block becomes critical in STBC-OFDM. Similarly, the channel gain might not be constant over neighboring subcarriers in SFBC-OFDM. When the constant channel assumption is not satisfied, the systems with orthogonal code suffer from interference in decoding process, which will be referred as intersymbol interference (ISI) hereinafter [4]. In other words, the system which utilizes only STBC-OFDM or SFBC-OFDM may suffer from significant performance degradation due to the ISI from channel fluctuation [5]. From this point of view, since the performance of STBC-OFDM and SFBC-OFDM show opposite characteristics in fading environments, the adaptive switching technique between STBC-OFDM and SFBC-OFDM is expected to provide remarkable performance improvement. However, few researches associated with switching technique between STBC-OFDM and SFBC-OFDM have been conducted. In this paper, we propose two new switching criteria that characterize the suitability of a given channel condition. First, from the observation of the theoretical performance in [6], we find that the higher correlation value yields higher SNR and better performance. As a result, for the first criterion, we compare the correlation between successive OFDM symbols for STBC-OFDM with the correlation between neighboring subcarriers for SFBC-OFDM, then choose the mode which has higher correlation value. Next, the magnitude of interference is used to derive the switching criterion. To reduce the performance degradation due to interference, we choose the transmission mode which has smaller interference. In this paper, we present an in-depth analysis of the performance of the zero forcing (ZF) and minimum mean squared error (MMSE) equalizers applied to the channel with adaptive switching system. The linear ZF and MMSE equalizers are classic functional blocks and are ubiquitous in digital communications [11]. They are also the building blocks of more advanced communication schemes such as the decision feedback equalizer (DFE), or equivalently, the V-BLAST (vertical Bell Labs layered Space-Time) architecture, and various other MIMO transceiver designs and the references .Despite their fundamental importance, however, the existing performance analyses of the ZF and MMSE equalizers are far from complete. For instance, it is commonly understood that ZF is a limiting form of MMSE as snr →∞. But when the ZF and MMSE are applied to the MIMO fading channel given in (11), one may observe through simulations that the error probabilities of MMSE and ZF do not coincide even as snr→∞. So here we have proposed an adaptive switching scheme that used ZF and MMSE equalizers which gives better performance than adaptive switching system with SML detector.

II. SYSTEM MODEL

Fig. 1 depicts a block diagram of the proposed system that adaptively switches between STBC-OFDM and SFBC-OFDM. The system consists of a transmitter with two antennas and a receiver with one antenna. The receiver estimates the channel state information and decides the appropriate transmission mode by using the proposed criteria. At the transmitter, it switches between STBC-OFDM and SFBC-OFDM that the feedback information from receiver indicates. The small bits feedback path for informing the mode and time/frequency synchronization of the system are assumed to be perfect. OFDM data are transmitted from two transmit antennas to one receive antenna, simultaneously. The *i*-th transmitted OFDM symbol from *g*-th transmitter is $\bar{X}_g[i]$. $\bar{X}_g[i]$ is converted to time domain by *N*-point inverse fast Fourier Transform (IFFT)

$$\bar{x}_g = F_N^H \bar{X}_g,$$

where F^H_N is the IDFT matrix. The *i*-th received OFDM symbol, $\bar{Y}_g[i]$, after fast Fourier Transform (FFT) processing at the receiver, is given by

$$\begin{aligned}\bar{Y}[i] &= [Y(1;i)Y(2;i)\cdots Y(k;i)\cdots Y(N;i)] \\ &= \bar{G}_1[i]\bar{X}_1[i] + \bar{G}_2[i]\bar{X}_2[i] - \bar{Z}[i],\end{aligned}$$

where $\bar{G}_g[i]$ is the *N* ×*N* frequency domain effective channel matrix between *g*-th transmitter and the receiver and $\bar{Z}[i]$ denotes the noise vector whose entry is zero-mean white complex
Gaussian random variable. Considering transformation from time-domain to frequency-domain by FFT, $\bar{G}_g[i]$ in (2) can be expressed as

$$\bar{G}_g[i] = F_N \bar{H}_g[i] F_N^H,$$

where $\bar{H}_g[i]$ is the *N* × *N* time domain effective channel matrix from the *g*-th transmitter to the receiver and F_N is *N*-point FFT matrix.
Assuming that *Na* subcarriers are active and $\mathbf{N_v = N - N_a}$ subcarriers are used for guard band, can be represented as

$$\bar{X}_g[i] = [0_{1\times N_v/2} \quad X_g[i]^T \quad 0_{1\times N_v/2}]^T,$$

where $X_g[i]$ is the $N_a \times 1$ data vector for $g \in \{1, 2\}$. Here, if we consider only the actual data at the receive antenna, (2) is reduced to

$$Y[i] = \Lambda_1[i]X_1[i] + \Lambda_2[i]X_2[i] + W[i],$$

where $Y[i]$ and $Z[i]$ are $N_{a\times 1}$ vectors, replicas of middle part of $\bar{Y}[i]$ and $\bar{Z}[i]$, respectively, and $G_g[i]$ is the $N_a \times N_a$ central block of

$\bar{\mathbf{G}}_g[i]$Considering the frequency domain effective channel matrix $\mathbf{G}_g[i]$, the off-diagonal terms are related to the inter-carrier interference (ICI) effects. Therefore, the received signal in (5) can be expressed in two parts: the main diagonal terms of channel matrix and off-diagonal terms related to ICI

$$\mathbf{Y}[i] = \mathbf{\Lambda}_1[i]\mathbf{X}_1[i] + \mathbf{\Lambda}_2[i]\mathbf{X}_2[i] + \mathbf{W}[i], \qquad (6)$$

where $\mathbf{\Lambda}_g[i]$ denotes a diagonal matrix, $\mathbf{\Lambda}_g[i] = D(\mathbf{G}_g[i])$, and

$$\mathbf{W}[i] = \mathbf{Z}[i] - (\mathbf{G}_1[i] - \mathbf{\Lambda}_1[i])\mathbf{X}_1[i] - (\mathbf{G}_2[i] - \mathbf{\Lambda}_2[i])\mathbf{X}_2[i].$$

That is, the vector $\mathbf{W}[i]$ contains the additive noise and ICI produced by the Doppler spread.

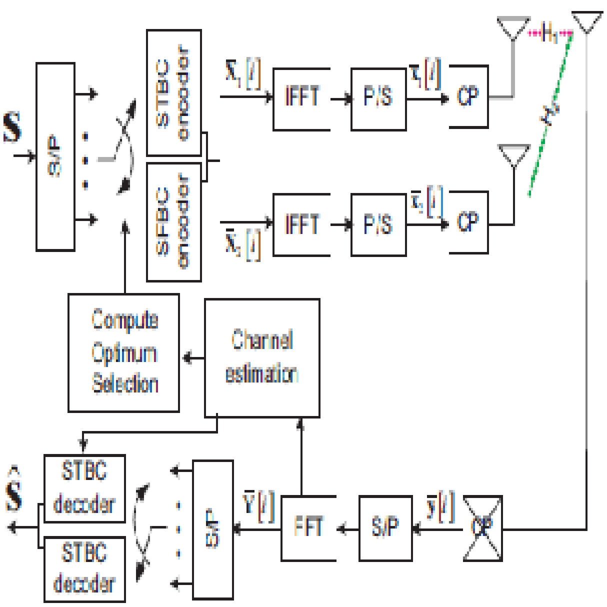


Fig. 1. Block diagram of the adaptive switching systems.

III. ALAMOUTI CODED OFDM SYSTEMS

A. STBC-OFDM

In the STBC-OFDM systems, the Alamouti scheme is applied over two successive OFDM symbols. The STBCOFDM encoder outputs are four $Na\times 1$ data vectors as follows:

$$\mathbf{X}_1[i] = [s_1 \;\; s_3 \;\; \cdots \;\; s_{2N_a-1}]^T,$$
$$\mathbf{X}_2[i] = [s_2 \;\; s_4 \;\; \cdots \;\; s_{2N_a}]^T,$$
$$\mathbf{X}_1[i+1] = [-s_2^* \;\; -s_4^* \;\; \cdots \;\; -s_{2N_a}^*]^T = -\mathbf{X}_2[i]^*,$$
$$\mathbf{X}_2[i+1] = [s_1^* \;\; s_3^* \;\; \cdots \;\; s_{2N_a-1}^*]^T = \mathbf{X}_1[i]^*.$$

At the receiver, two consecutive received signals, $\mathbf{Y}[i]$ and $\mathbf{Y}[i+1]$, are used to decode transmitted symbols in the STBC-OFDM systems. If we consider only the received signals on k-th subcarrier, the received signal vectors during two time slots are,

$$\tilde{\mathbf{Y}} = \tilde{\mathbf{\Lambda}}\tilde{\mathbf{X}} + \tilde{\mathbf{W}},$$

where

$$\tilde{\mathbf{Y}} = [Y(k;i) \;\; Y(k;i+1)^*]^T,$$
$$\tilde{\mathbf{\Lambda}} = \begin{bmatrix} \Lambda_1[i;k] & \Lambda_2[i;k] \\ \Lambda_2[i+1;k]^* & -\Lambda_1[i+1;k]^* \end{bmatrix},$$
$$\tilde{\mathbf{X}} = \begin{bmatrix} X_1(k;i) \\ X_2(k;i) \end{bmatrix}, \quad \tilde{\mathbf{W}} = \begin{bmatrix} W(k;i) \\ W(k;i+1)^* \end{bmatrix}.$$

Multiplying $\tilde{\mathbf{\Lambda}}^H$ on the both sides of (9) yields

$$\hat{\mathbf{X}} = \tilde{\mathbf{\Lambda}}^H\tilde{\mathbf{Y}} = \tilde{\mathbf{\Lambda}}^H\tilde{\mathbf{\Lambda}}\tilde{\mathbf{X}} + \tilde{\mathbf{\Lambda}}^H\tilde{\mathbf{W}},$$

where

$$\tilde{\mathbf{\Lambda}}^H\tilde{\mathbf{\Lambda}} = \begin{bmatrix} \alpha_{ST1} & \beta_{ST} \\ \beta_{ST}^* & \alpha_{ST2} \end{bmatrix},$$

and α_{ST} and β_{ST} are given by

$$\alpha_{ST} \simeq \alpha_{ST1(2)} = |\Lambda_{1(2)}[i;k]|^2 + |\Lambda_{2(1)}[i+1;k]|^2,$$
$$\beta_{ST} = \Lambda_1[i;k]^*\Lambda_2[i;k] - \Lambda_1[i+1;k]^*\Lambda_2[i+1;k]$$

Under the assumption of constant channel coefficients during transmission block, $\hat{}$ becomes orthogonal matrix, i.e., β_{ST} is equal to zero, thus ZF equalizer decouples the transmitted symbols perfectly. However, when the orthogonality is lost, ZFE introduces ISI. Therefore, in fast fading environments, STBC over successive OFDM symbols cannot avoid the performance degradation.

B. SFBC-OFDM

The Alamouti scheme is applied across two neighboring tones for SFBC-OFDM systems. The SFBC-OFDM encoder is represented as two $N_a \times 1$ data vectors,

$$\mathbf{X}_1[i] = [s_1 \quad -s_2^* \quad s_3 \quad -s_4^* \quad \cdots \quad s_{N_a-1} \quad -s_{N_a}^*]^T,$$
$$\mathbf{X}_2[i] = [s_2 \quad s_1^* \quad s_4 \quad s_3^* \quad \cdots \quad s_{N_a} \quad s_{N_a-1}^*]^T. \qquad (12)$$

From (12), we know that received signals on neighboring subcarriers, k-th and $(k + 1)$th , where k is odd number, are used to decode transmitted symbols. The received signal vector of SFBC-OFDM is

$$\tilde{\mathbf{Y}} = \tilde{\Lambda}\tilde{\mathbf{X}} + \tilde{\mathbf{W}},$$

where

$$\tilde{\mathbf{Y}} = [Y(k;i) \quad Y(k+1;i)^*]^T,$$
$$\tilde{\Lambda} = \begin{bmatrix} \Lambda_1[i;k] & \Lambda_2[i;k] \\ \Lambda_2[i;k+1]^* & -\Lambda_1[i;k+1]^* \end{bmatrix};$$
$$\tilde{\mathbf{X}} = \begin{bmatrix} X_1(k;i) \\ X_2(k;i) \end{bmatrix} = \begin{bmatrix} X_2(k+1;i)^* \\ -X_1(k+1;i)^* \end{bmatrix};$$
$$\tilde{\mathbf{W}} = [W(k;i) \quad W(k+1;i)^*]^T.$$

Multiplying $\tilde{\Lambda}^H$ on the both sides of (13) yields,

$$\hat{\mathbf{X}} = \tilde{\Lambda}^H\tilde{\mathbf{Y}} = \tilde{\Lambda}^H\tilde{\Lambda}\tilde{\mathbf{X}} + \tilde{\Lambda}^H\tilde{\mathbf{W}}, \qquad (14)$$

where

$$\tilde{\Lambda}^H\tilde{\Lambda} = \begin{bmatrix} \alpha_{SF1} & \beta_{SF} \\ \beta_{SF}^* & \alpha_{SF2} \end{bmatrix}, \qquad (15)$$

and α_{SF} and β_{SF} are given by

$$\alpha_{SF} \simeq \alpha_{SF1(2)} = |\Lambda_{1(2)}[i;k]|^2 + |\Lambda_{2(1)}[i;k+1]|^2,$$
$$\beta_{SF} = \Lambda_1[i;k]^*\Lambda_2[i;k] - \Lambda_1[i;k+1]^*\Lambda_2[i;k+1].$$

While STBC-OFDM systems face problems in fast fading environments, SFBC-OFDM systems suffer from the frequency-selectivity of fading channel. To maintain the orthogonality of effective channel matrix, the frequency channel response needs to be constant over two neighboring subcarriers in SFBC-OFDM systems. Otherwise, the orthogonality is lost,i.e., β_{SF} in (15) is not equal to zero, and the performance of SFBC-OFDM is degraded due to ISI in decoding process.

IV. PROPOSED ADAPTIVE SPACE-TIME/FREQUENCY CODED OFDM SYSTEMS.

In this section, two selection criteria are proposed to choose the appropriate transmission mode at the given channel condition. In [8], the selection criterion was found from empirical searching by comparing the bit error rate curves of STBCOFDM and SFBC-OFDM. Then, the switching criterion was approximated by the use of fitting method with first order polynomial. However, because this approach is based on empirical data and fitting method, it has lots of limitations. In this paper, we propose two new switching criteria that characterize the suitability of a given channel condition. We select the mode by comparing the correlation of the channel for STBC-OFDM with that for SFBC-OFDM in subsection A, and the magnitude of interference of STBC-OFDM with that of SFBC-OFDM in subsection B.

Criterion I : correlation of the channel

In this criterion, the correlation between adjacent blocks for the same subcarrier, ρ_t, and the correlation between adjacent subcarriers for the same block, ρ_f , are compared to choose an appropriate transmission mode. In [6] and [7], the performance of STBC-OFDM and SFBC-OFDM with SML detector in time-varying multipath channel were derived. The results are based on the computed effective average

SNR of STBCOFDM, γ_{ST}, and of SFBC-OFDM, γ_{SF}. They are represented as

$$\gamma_{ST} = \frac{2\sigma_H^2 E_S}{[\sigma_H^2 E_S(1 - |\rho_t|^2) + \sigma_W^2]},$$
$$\gamma_{SF} = \frac{2\sigma_H^2 E_S}{[\sigma_H^2 E_S(1 - |\rho_f|^2) + \sigma_W^2]}.$$

Since the performance of the system is a function of the effective SNR, maximizing the SNR yields the best performance. To maximize the SNR at the receiver, the larger correlation value in (16) and (17) is preferred. In this sense, selection of the proper transmission mode which has larger SNR between STBC-OFDM and SFBC-OFDM is equivalent to the selection of the mode which has higher correlation values in (16) and (17). Consequently, the mode selection criterion can be represented as

$$|\rho_t| \underset{\text{SFBC}}{\overset{\text{STBC}}{\gtrless}} |\rho_f|.$$

In [9], the theoretical value of ρt and ρf are derived, but this results are valuable only when the channel is assumed exponential power-delay profile with classical Doppler spectrum. Therefore, instead of that, we calculate the correlation values by using the channel gain. The correlation between adjacent blocks for the same subcarrier, which indicates the suitability of STBC-OFDM, is

$$|\rho_t| = E\left[\mathbf{\Lambda}[i;k]\mathbf{\Lambda}[i+1;k]^*\right], \qquad (19)$$

and the correlation between adjacent subcarriers for the same block, which indicates the suitability of SFBC-OFDM, is

$$|\rho_f| = E\left[\mathbf{\Lambda}[i;k]\mathbf{\Lambda}[i;k+1]^*\right]. \qquad (20)$$

B. Criterion II :Magnitude of the interference

The Alamouti scheme is regarded as the best transmit diversity technique because of some reasons including its decoding simplicity. However, we are here using adapting equalization techniques (ZF and MMSE) which shows the minimum interference and high SNR only when the channel coefficients during transmission block are the same. Otherwise, the orthogonality of the code is lost and the interference, β_{ST} or β_{SF}, are introduced.

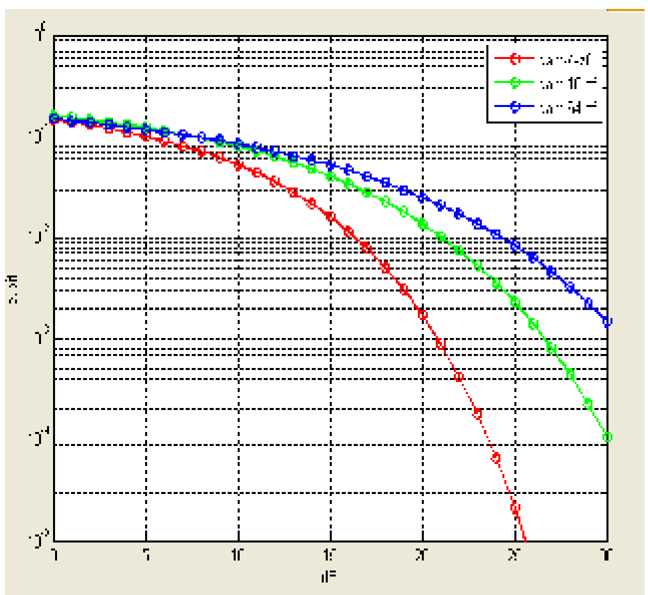
$\beta_{ST} = \mathbf{\Lambda}_1[i; k] * \mathbf{\Lambda}_2[i; k] - \mathbf{\Lambda}_1[i + 1; k] * \mathbf{\Lambda}_2[i + 1; k]$, (21)

$\beta_{SF} = \mathbf{\Lambda}_1[i; k] * \mathbf{\Lambda}_2[i; k] - \mathbf{\Lambda}_1[i; k + 1] * \mathbf{\Lambda}_2[i; k + 1]$. (22)

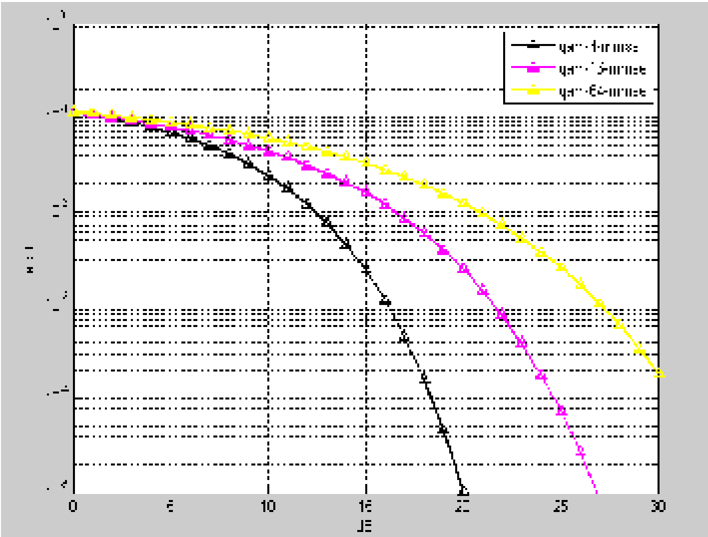
As aforementioned in III, the interference β_{ST} and β_{SF} induce the performance degradation of STBC-OFDM and SFBC-OFDM, respectively. From this point of view, the mode with smaller interference would show better performance. Therefore, the adaptive switching algorithm also can be operated by comparing the magnitude of the interference in STBC-OFDM with that in SFBC-OFDM.

V. SIMULATION RESULTS

Simulation result shows comparing the adaptive switching based OFDM system using ZF and MMSE equalizers, the performance of system improved with QAM scheme and results shows ZF gives better SNR performance than MMSE .



Adaptive Switching based OFDM system using ZF Technique



Adaptive Switching based OFDM system using MMSE Technique

The bandwidth of 1MHz is divided into total 128 sub channels, N, with 96 active subcarriers, N_a, and the carrier frequency is 2.3GHz. We set the length of CP to 1/4 of the symbol duration, i.e., $32\mu s$. Thus, the OFDM symbol duration is $160\mu s$. The modulation scheme for all subcarriers of the OFDM symbol is QAM with different bit size (4/16/64).

VI. CONCLUSION

We investigate two different methods of equalization (ZF,MMSE) for adaptive switching system between STBC-OFDM and SFBC-OFDM based on two criteria. The first criterion is based on the correlation value of the channel gain and the second criterion is based on the magnitude of the interference. Based on the proposed criteria, we showed that the proposed adaptive switching system provides performance improvement over adaptive system with SML detector and shows even better performance in the high SNR regime.

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