SPACE FREQUENCY BLOCK CODED OFDM SYSTEMS WITH ADAPTIVE MODULATION AND IMPROVED ANTENNA SELECTION

A Thesis by

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B.E., Osmania University, 2004

Submitted to the Department of Electrical Engineering
and the faculty of Graduate School of
Wichita State University
in partial fulfillment of
the requirements for the degree of
Master of Science

December 2005

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The following faculty members have examined the final copy of this Thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science with a major in Electrical Engineering.

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Edwin M. Sawan, Committee Member

Krishna Krishnan, Committee Member

DEDICATION

This thesis is dedicated to my parents, Mr. K. Rama Krishna Reddy and Mrs. K. Rukmini, my grand parents, Mr. P. Desai Reddy and Mrs. P. Ananthalaxmi and to my loving brother.

ACKNOWLEDGEMENTS

Firstly, I would like to thank my advisor Dr. Hyuck M. Kwon for his personal attention, care, encouragement and invaluable guidance during the course of my study at Wichita State University. I would also like to thank my committee members Dr. Edwin M. Sawan and Dr. Krishna Krishnan, for their comments and valuable time.

I would like to thank Srinivas Rao Vaidya for his valuable insight and technical help. I would like to thank Wireless communication group members for their extended support and cooperation. And finally I would like to thank my dear friends as well my room mates, Dr. Shashidar Seshani, Vinay Pampati, Kiran Kanukuntla, Kiran Bodapati and my loved ones for their encouragement and support.

ABSTRACT

This thesis proposes a new antenna selection scheme for the conventional space-frequency block code (SFBC) - orthogonal frequency division multiplexing (OFDM) system using adaptive modulation. In the proposed scheme, the antenna selection criterion is based on fading coefficients at all frequency components instead of Frobenius norms. The best fading coefficient is chosen at each frequency for different antennas, and then data is sent on those antennas with the best fading coefficients at that particular frequency. The coding and diversity advantages of the proposed system are examined. It is shown that this new antenna selection scheme greatly improves the performance of the conventional SFBC-OFDM system, which is a significant achievement.

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CHAPTER 1

INTRODUCTION

1.1 Motivation

The diversity gain can be increased by the use of multiple antennas at transmitter and receiver [1] [2] [3] [4]. The scheme proposed by Alamouti [1] greatly improves the performance of the system over flat fading channels. Space time codes were used to significantly improve the data rate and also reduce the error rate thus improving the performance of communication channel [5] [6] [7]. Space frequency Block codes were shown to be much effective in frequency selective fading channels as the code is simultaneously transmitted on neighboring sub carriers [8] [9]. The orthogonal frequency- division multiplexing (OFDM) when used with frequency selective fading, converts the channel into several flat fading channels, i.e., the channel impulse response can be considered flat within each sub channel [10] [11]. The advantages of combining Space frequency Block coding with OFDM were explored [12]. The benefits of using Adaptive modulation techniques over OFDM systems using Space Frequency Block codes and Antenna selection has been exploited to enhance the quality of transmission of broadband wireless communications [13].A new antenna selection is proposed in this thesis and is shown to be an efficient technique to improve performance and reduce complexity of the system. The proposed system uses an efficient and elegant antenna selection scheme which makes use of the best fading coefficients to transmit data at different frequencies.

1.2 Contribution

In the proposed scheme, the antenna selection criterion is based on fading coefficients at all frequency components instead of Frobenius norms. The best fading coefficient is chosen at each frequency for multiple antennas, and an attempt is made to send data on those antennas with the best fading coefficients at each particular frequency. The proposed antenna selection scheme is evaluated analytically and is shown to have remarkable improvement in diversity. Here we consider Alamouti space codes for multiple antennas at the transmitter and a single antenna at the receiver. The purpose behind this idea is to reduce the bit error rate, as compared to the conventional system that is based on Frobenius norms, introducing no additional complexity.

1.3 Organization

This thesis is organized into seven chapters. The first chapter gives a brief introduction and motivation behind this idea. The system model is presented in the second chapter, followed by the antenna selection scheme in chapter three. The review of space frequency block coding (SFBC) with orthogonal frequency division multiplexing is presented in chapter four followed by the adaptive modulation concept in chapter five. The sixth chapter covers simulation results as well a brief comparison of the results. Finally, the conclusion and the future scope of this idea are presented in the seventh chapter.

CHAPTER 2

SYSTEM MODEL

The block diagram of the proposed system is shown in Figure 2.1. The data is first converted from serial to parallel and then antenna selection is made based on the proposed scheme. Adaptive modulation uses the water filling scheme. If the channel is good, higher modulation schemes are used and vice versa. The adaptive modulated bits S(n) are then coded using SFBC. The output of SFBC encoder is then subjected to OFDM and then transmitted over selected antennas. At the receiver end the reverse process is carried out, i.e., the received data is decoded using SFBC decoder $\tilde{S}(n)$, and then demodulated to get the transmitted data. The demodulated data is then converted from parallel to serial.

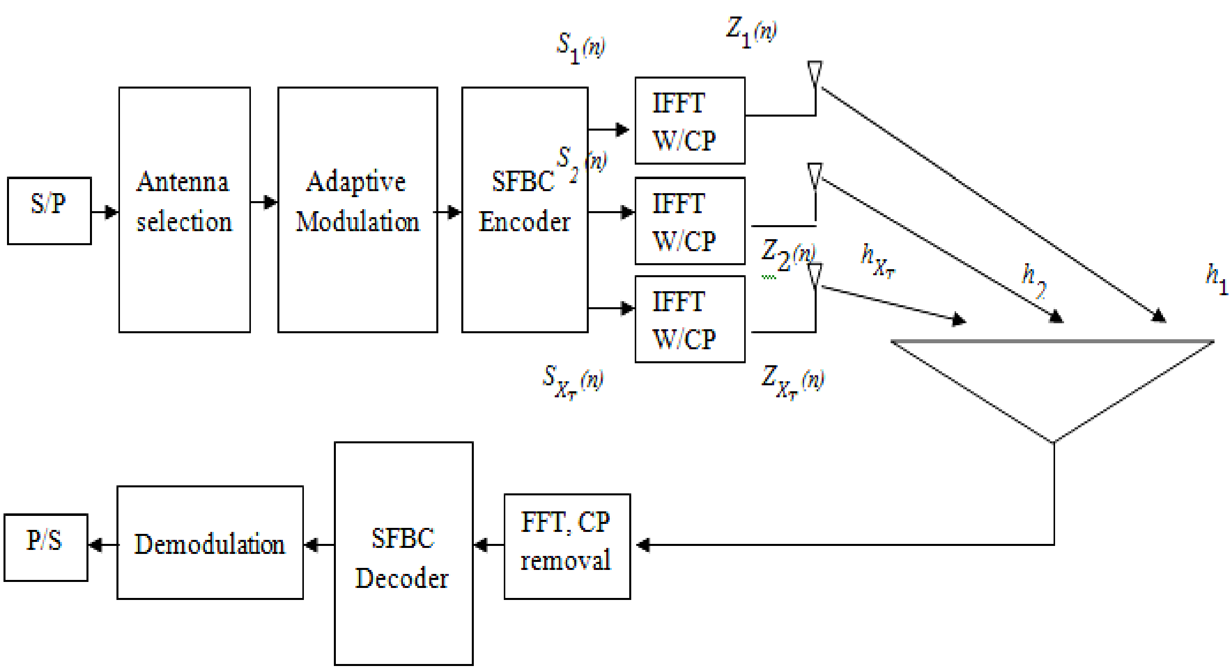

Figure 2.1 Block diagram of SFBC-OFDM with antenna selection.

CHAPTER 3

ANTENNA SELECTION

Generally antenna selection is based on Frobenius norms. Supposing that there are total X_T antennas, Y_T of them are selected based on Frobenius norms, e.g., $X_T X_T{}^T = \|X_T\|^2$ for the column vector X_T where the superscript T denotes the transpose and $\|X_T\|$ is the norm of the vector X_T. Assuming X_T transmitter antennas and a single antenna at the receiver, the mth sub carrier response in the nth time block $H[n,m]$ would be a $(X_T \times 1)$ matrix, given by

$$H[n,m] = [H_1[n,m] \quad H_2[n,m] \quad H_3[n,m] \quad H_{X_T}[n,m]]. \tag{3.1}$$

In the general antenna selection based on Frobenius norms, the Frobenius norm is calculated for each antenna based on channel coefficients and are then arranged in descending order [1] [2] [3] [4]. The Y_T antennas with the highest Frobenius norms are selected. In this case $(X_T \times 1)$ antenna selection is selecting Y_T columns with the highest Frobenius norms. Hence, the selected sub channel matrix is of order $(Y_T \times 1)$ given by

$$H^S[n,m] = [H^S{}_1[n,m] \quad H^S{}_2[n,m] \quad H^S{}_3[n,m] \quad H^S{}_{Y_T}[n,m]]. \tag{3.2}$$

On the other hand, the proposed scheme is shown in Figure 3.1. In this scheme, instead of averaging the overall frequency components, i.e., using Frobenius norms, the channel fading coefficients of X_T antennas given at particular frequency are considered, and Y_T antennas are selected with highest channel coefficients arranged in descending order. This is done at each subcarrier, and the Y_T antennas with the highest channel coefficients are selected at each frequency, i.e., the best antennas are chosen at each frequency to transmit the data.

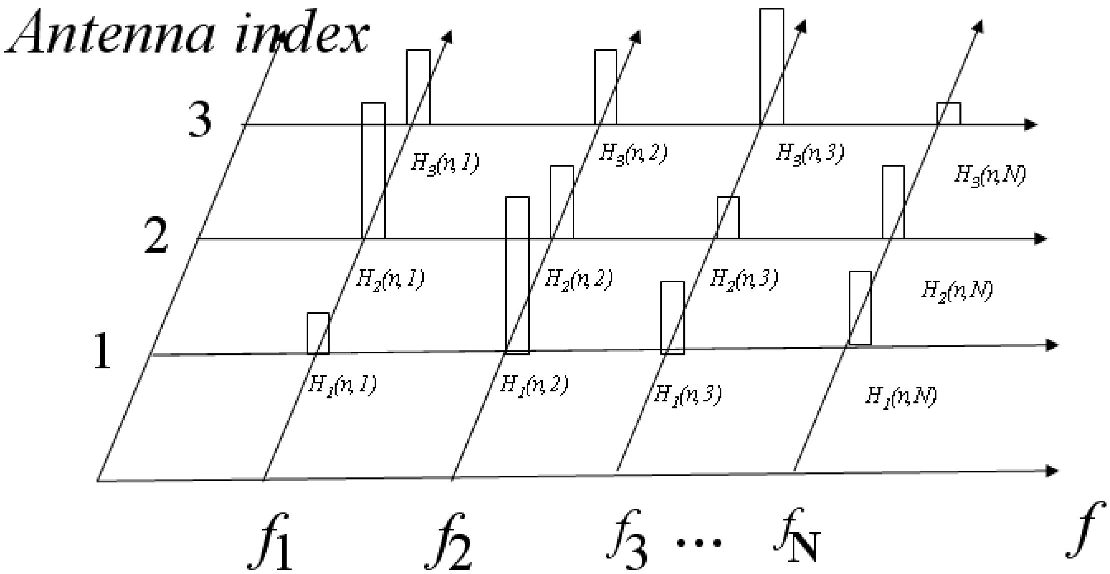

Figure 3.1 Block diagram of antenna selection scheme.

3.1 General Scheme (Frobenius Norms)

For example, using figure 3.1, $X_T = 3$, selecting two antennas out of three, i.e., $Y_T = 2$, we calculate

$$\left|H_1[n]\right|^2 = \left|H_1[n,1]\right|^2 + \left|H_1[n,2]\right|^2 + \left|H_1[n,3]\right|^2 + \ldots.. + \left|H_1[n,N]\right|^2 \tag{3.3}$$

$$\left|H_2[n]\right|^2 = \left|H_2[n,1]\right|^2 + \left|H_2[n,2]\right|^2 + \left|H_2[n,3]\right|^2 + \ldots.. + \left|H_2[n,N]\right|^2 \tag{3.4}$$

$$\left|H_3[n]\right|^2 = \left|H_3[n,1]\right|^2 + \left|H_3[n,2]\right|^2 + \left|H_3[n,3]\right|^2 + \ldots.. + \left|H_3[n,N]\right|^2 \ . \tag{3.5}$$

By arranging the channel magnitude coefficients of antennas in descending order

$$|H_2[n]|^2 > |H_1[n]|^2 > |H_3[n]|^2 \tag{3.6}$$

the first two antennas with higher channel magnitude coefficients are selected and are used to transmit the data.

3.2 Proposed Scheme

In the proposed scheme, antenna selection is done at each frequency component instead of using Frobenius norms. At each frequency, the channel coefficients are arranged in descending order and the best of them are chosen to transmit the data.

At frequency

f_1 : if $H_2[n,1] > H_3[n,1] > H_1[n,1]$, then antennas 2 and 3 are selected.

f_2 : if $H_1[n,1] > H_2[n,1] = H_3[n,1]$, then antennas 1 and 2 (or) 3 are selected

f_3 : if $H_3[n,1] > H_1[n,1] > H_2[n,1]$, then antennas 3 and 1 are selected.

f_N : if $H_1[n,1] = H_2[n,1] > H_3[n,1]$, then antennas 1 and 2 are selected.

CHAPTER 4

SFBC-OFDM

4.1 Introduction

Wireless broadband systems offer different sources of diversity, which can be properly exploited by a proper coding and transmission scheme. Multiple antennas and space time codes can be used to obtain spatial diversity [5] [6] [7]. A forward error correction (FEC) decoder with interleaving can be used to pick up temporal diversity. Frequency diversity can be utilized by an equalizer or by an FEC decoder in an orthogonal frequency division multiple access system.

The maximum diversity can be realized using the Space-time block codes proposed by Alamouti [1] and Tarokh et al. [6] which provide a simple transmit diversity scheme in a flat fading multiple-input multiple (MIMO) channel. In this thesis a simple decoder is applied at the receiver to decode the symbols transmitted simultaneously from different antennas, given that the channel is static during transmission of one orthogonal symbol. The available MIMO techniques are very useful in flat frequency channels. OFDM converts a wide band frequency to multiple narrow bands which almost have flat frequency. So we can use MIMO with OFDM to transmit data in wide band frequencies achieving high efficiency and low bit error rate. Space time or space frequency along with OFDM can utilize the orthogonal transmission by Alamouti [1].

A cyclic guard interval (GI) is inserted at each antenna in OFDM thus providing flat fading channel for each sub carrier. Therefore, space-time block codes can be used in conjunction with OFDM. However, in the frequency-selective broadband channels, as the broadband channel is subdivided into orthogonal narrowband channels, the symbol duration is increased significantly as compared to that of single carrier of the same total bandwidth. The use of space frequency block code is beneficial because code is transmitted here on neighboring sub carriers [8] [9]. Space frequency block code has the better performance compared to space- time block coding in highly varying environments, i.e., where the channel varies too quickly [12]. In slow varying channels the performance of space frequency as well as space time block codes are the same. The space time block coding or space frequency block coding can be used in conjunction with OFDM to achieve higher signal to noise ratio.

4.2 Orthogonal Frequency Division Multiplexing (OFDM)

Multiple signals can be transmitted at the same time on a specific path using frequency division multiplexing. Each of the transmitted signals has its own unique frequency. The information is modulated with these transmitted signals. Frequency division multiplexing combined with orthogonal spread spectrum technique can be used to place the data over carriers that are spaced apart at different frequencies. The receivers are configured to detect data at their own specific frequency thus reducing signal overlap and reduce the bit error rate. High Spectral efficiency can be achieved using OFDM [10].RF interference and distortion can also be lowered by using OFDM. This technology is extremely useful in broadcasting. [11]

Rectangular pulse is used in OFDM transmission. The signal can be modulated at transmitter using Inverse Fourier and demodulated using Fourier transform.

The subcarriers spectrums overlap in OFDM. Using this orthogonality principle, we can separate the transmitted data over the carriers at the receiver. The spacing of the subcarriers is of prime importance. They should be chosen such that the signals other than original signal have signal strength as zero at the specific frequency. This is done using Inverse Fourier transform.

As the ideal orthogonality cannot be achieved using the devices (transmitter/receiver) and also the channel undergoes constant fading, the OFDM symbols are also enhanced by repeating the adding tail portion of the symbol periodically and preceding the symbol with it. The guard time interval introduced at the transmitter is then later removed at the receiver. The orthogonality is preserved by making the guard time interval longer than max channel delay. The distortion to the signal caused by channel can be almost removed by dividing with the transfer function of the channel.

4.3 Space Frequency Block Codes

For simplicity, first consider two transmit antennas ($Y_T = 2$) and a single receive antenna. The SFBC code for this case is as

$$M_2 = \begin{pmatrix} +s[n,2m] & +s[n,2m+1] \\ -s^*[n,2m+1] & +s^*[n,2m] \end{pmatrix} = \left(s_1[n,m] \quad s_2[n,m] \right) \tag{4.1}$$

The space- frequency coded blocks $S_1[n,m]$ and $S_2[n,m]$ can be extended as

$$S_1(n) = (+S[n,0], -S^*[n,1], +S[n,2], -S^*[n,3], \ldots.., +S[n,N-2], -S^*[n,N-1])^T \tag{4.2}$$

$$S_2(n) = (+S[n,1], +S^*[n,0], +S[n,3], +S^*[n,2], \ldots.., +S[n,N-1], +S^*[n,N-2])^T \tag{4.3}$$

The OFDM block then generates blocks Z_1 and Z_2, using space-frequency coded blocks $S_1[n,m]$ and $S_2[n,m]$ as inputs. These blocks are then transmitted over the selected antennas.

The received vector after FFT can be given as

$$R(n) = H_1^{\ S}(n)S_1(n) + H_2^{\ S}(n)S_2(n) + D(n) \tag{4.4}$$

where $D(n)$ is the additive white Gaussian noise with zero mean and σ^2 variance. Here the maximum likelihood rule is used to decode the data. Hence, the output of the SFBC decoder is

$$\tilde{S}[n,2m] = H_1^{\ S^*}[n,2m]R[n,2m] + H_2^{\ S}[n,2m]R^*[n,2m+1] \tag{4.5}$$

$$\tilde{S}[n,2m+1] = H_2^{\ S^*}[n,2m]R[n,2m] - H_1^{\ S}[n,2m]R^*[n,2m+1]. \tag{4.6}$$

Substituting the received signal vectors and assuming channel is quasistatic for at least two symbol periods gives

$$\tilde{S}[n,2m] = (\left|H_1^{\ S}[n,2m]\right|^2 S_1[n,2m] + \left|H_2^{\ S}[n,2m]\right|^2 S_2^{\ *}[n,2m+1] + H_1^{\ S^*}[n,2m]D[n,2m] + H_2^{\ S}[n,2m]D^*[n,2m+1] \tag{4.7}$$

$$\tilde{S}[n,2m+1] = (\left|H_1^{\ S}[n,2m]\right|^2 S_1^{\ *}[n,2m+1] + \left|H_2^{\ S}[n,2m]\right|^2 S_2[n,2m] - H_1^{\ S}[n,2m]D[n,2m+1] + H_2^{\ S^*}[n,2m]D\ [n,2m] \tag{4.8}$$

Clearly (4.7) and (4.8) show the diversity gain offered by multiple antennas at the transmitter. At the end, the elements of each block are demodulated to obtain data.

CHAPTER 5

ADAPTIVE MODULATION

5.1 Introduction

In this chapter, we will introduce the concept of adaptive modulation (AM). AM provides good use of the channel than conventional fixed modulation methods. Adaptive modulation utilizes fading characteristics. A choice can be done between spectral efficiency and bit error rate. Higher modulation can be used for lower fades causing high data rate and low bit error rate and vice versa [13].

.

5.2 Adaptive Scheme

The water filling scheme is employed here using the appropriate modulation based on channel statistics. If the channel is good, a higher modulation is used and if it is bad, lower modulation schemes are used. For simplicity only two modulations are used: binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK).

The spectral efficiency is defined as the number of information bits encoded on a modulated transmission symbol. The performance of adaptive modulation is discussed in terms of bit error rate or spectral efficiency. The theoretical plot of spectral efficiency is as shown in Figure 5.1.

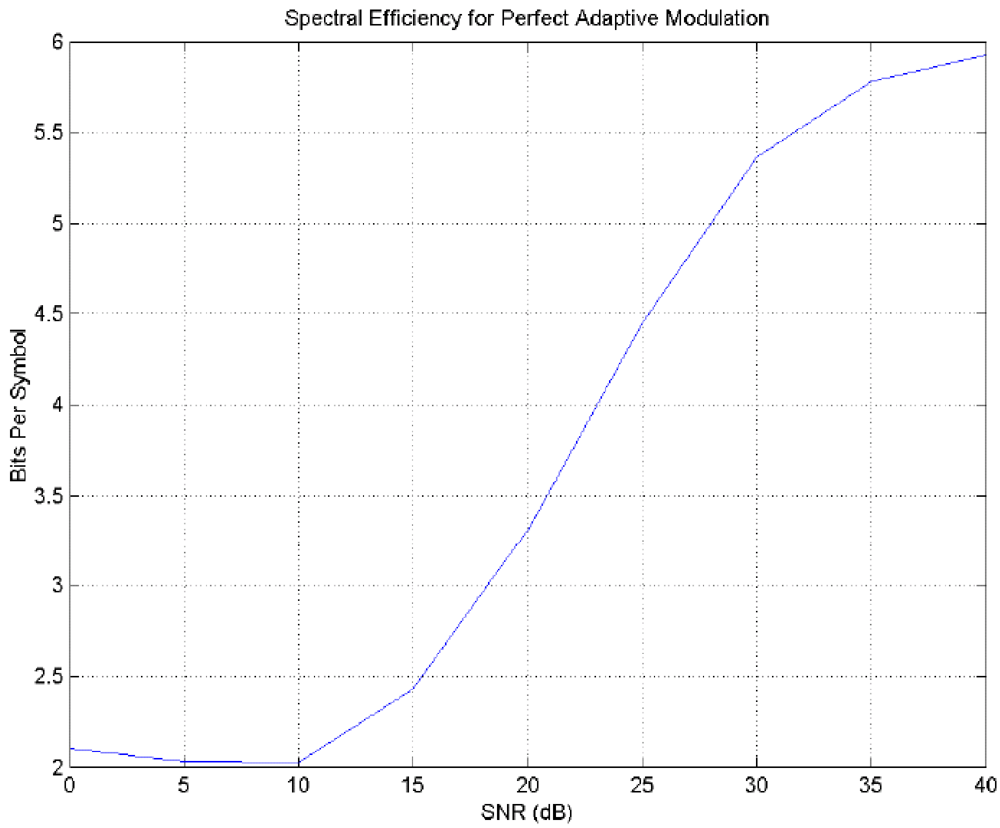

Figure 5.1 – Spectral efficiency for perfect adaptive modulation vs. average SNR for a Rayleigh fading channel.

Figure 5.1 shows a plot of the spectral efficiency of adaptive modulation versus the average SNR in dB. At low SNR, the system achieves two bits per symbol, since as QPSK is primarily used. However, as the SNR increases, the throughput also improve steadily, which indicates that more spectrally efficient modulation schemes are being used.

The curve begins to level out close to 30 dB, since 64 QAM becomes the modulation scheme used most often. As the SNR improves, the system is better able to choose more efficient modulation schemes. Different modulation schemes can be used to increase throughput and decrease bit error rate. For example, if there is enormous fading, it makes sense to transmit less number of bits so that the bit error is less. And similarly if the channel is not fading, more number of bits can be sent over the channel increasing the efficiency of the channel and decreasing error rate. The combination of these two principles allows the BER performance of adaptive systems to be more effective than static systems, while simultaneously providing better spectral efficiency at most ranges of SNR.

CHAPTER 6

SIMULATION RESULTS

The proposed scheme is simulated in a Rayleigh fading environment with additive white Gaussian noise. Figure 6.1 compares the performance of a QPSK- modulated SFBC-OFDM system with a BPSK- modulated SFBC-OFDM system. As shown, QPSK is 1 dB worse than BPSK.

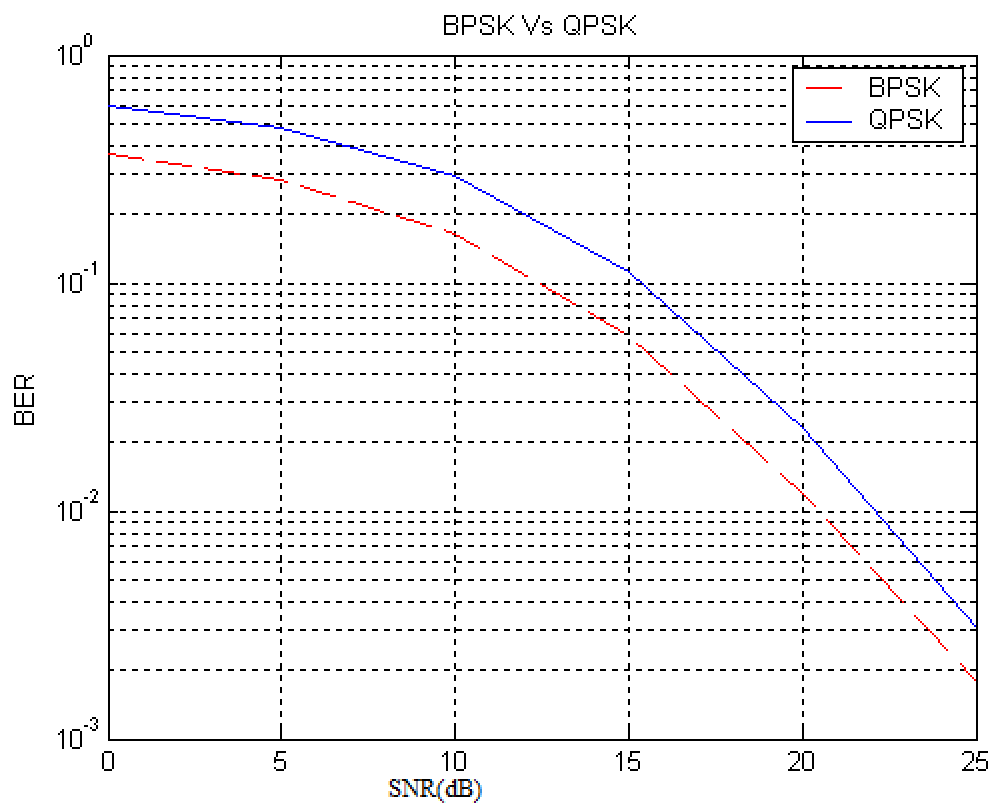

Figure 6.1 QPSK-SFBC-OFDM vs. BPSK-SFBC-OFDM (2 TX- 1 RX)

Figure 6.2 compares the performance of the proposed SFBC-OFDM- aided antenna selection with a conventional SFBC-OFDM system for two modulations, BPSK and QPSK. As shown there is a 5 dB improvement over the conventional system in both cases.

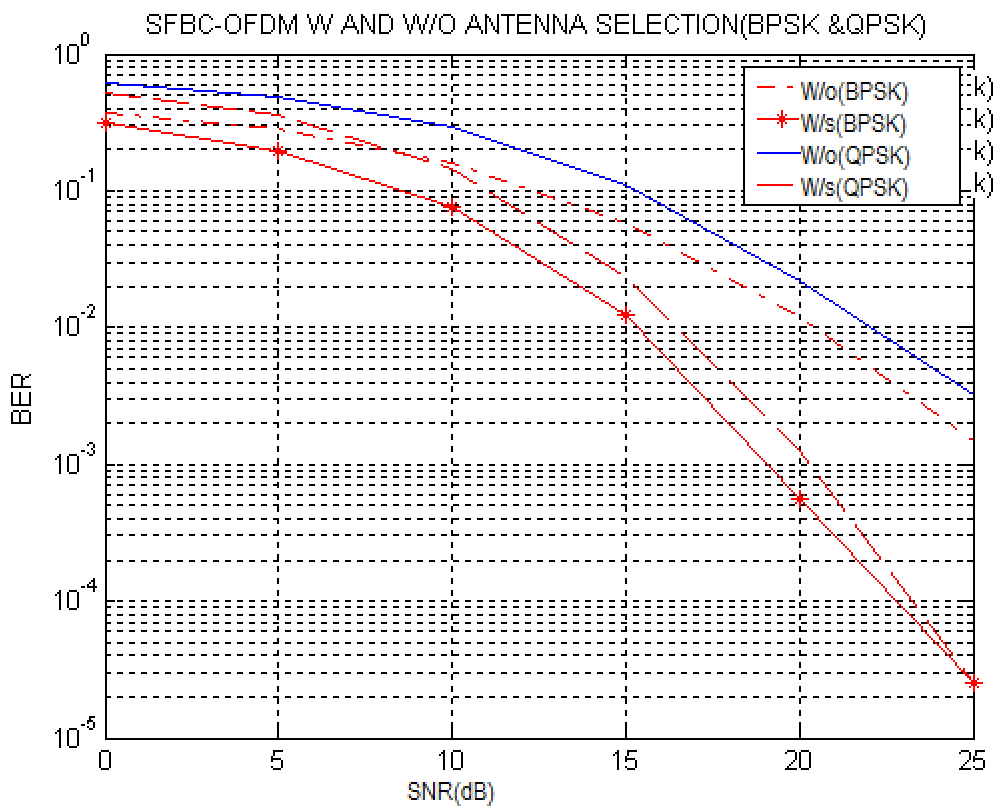

Figure 6.2 SFBC-OFDM W/ (2 TX- 4TX) and SFBC-OFDM without Antenna selection.

Figure 6.3 compares the performance of equal power-distributed and unequal power-distributed TX antennas. As shown, that there is a 1 dB gain for unequal power distribution.

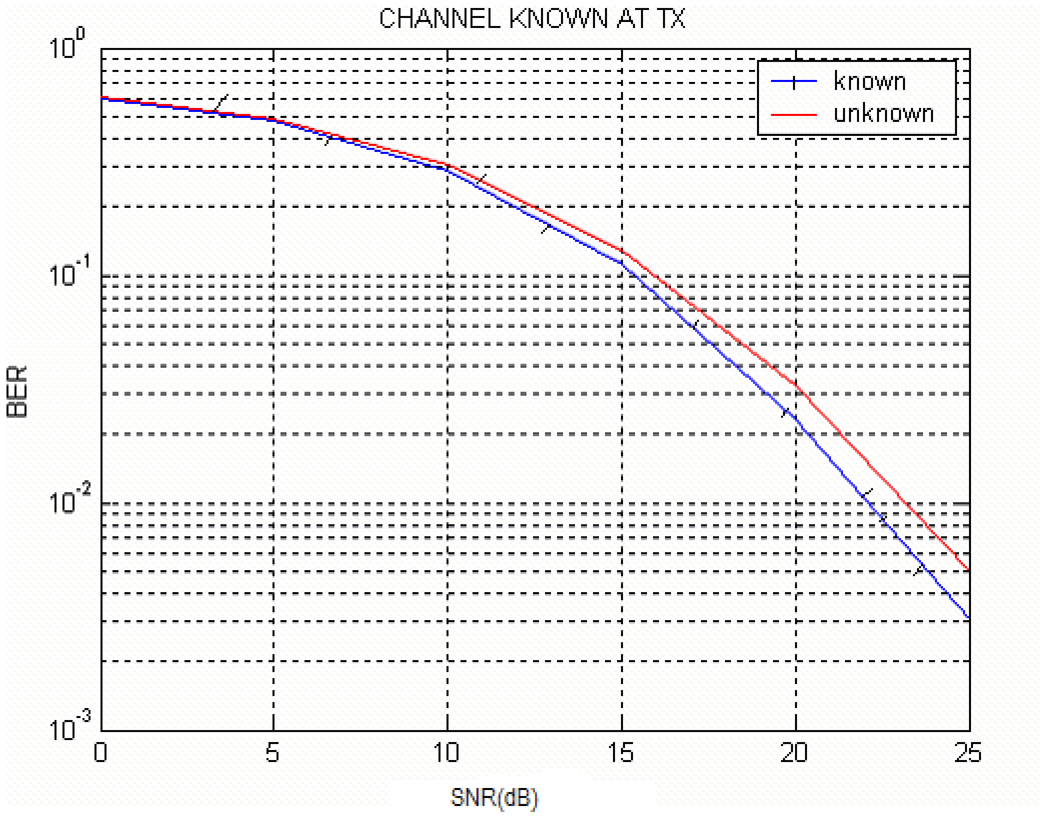

Figure 6.3 Unequal power distributions to antennas (2 TX-1RX).

Figure 6.4 compares the performance of an adaptive modulated SFBC-OFDM system with BPSK and QPSK modulated systems. As shown there is an improvement of 2.5 dB with the adaptive scheme, when compared to BPSK with non-adaptive, and about 5 dB when compared with QPSK with non-adaptive at a lower SNR. But as SNR increases, the adaptive system becomes the same as BPSK but still has a 1 dB gain over QPSK.

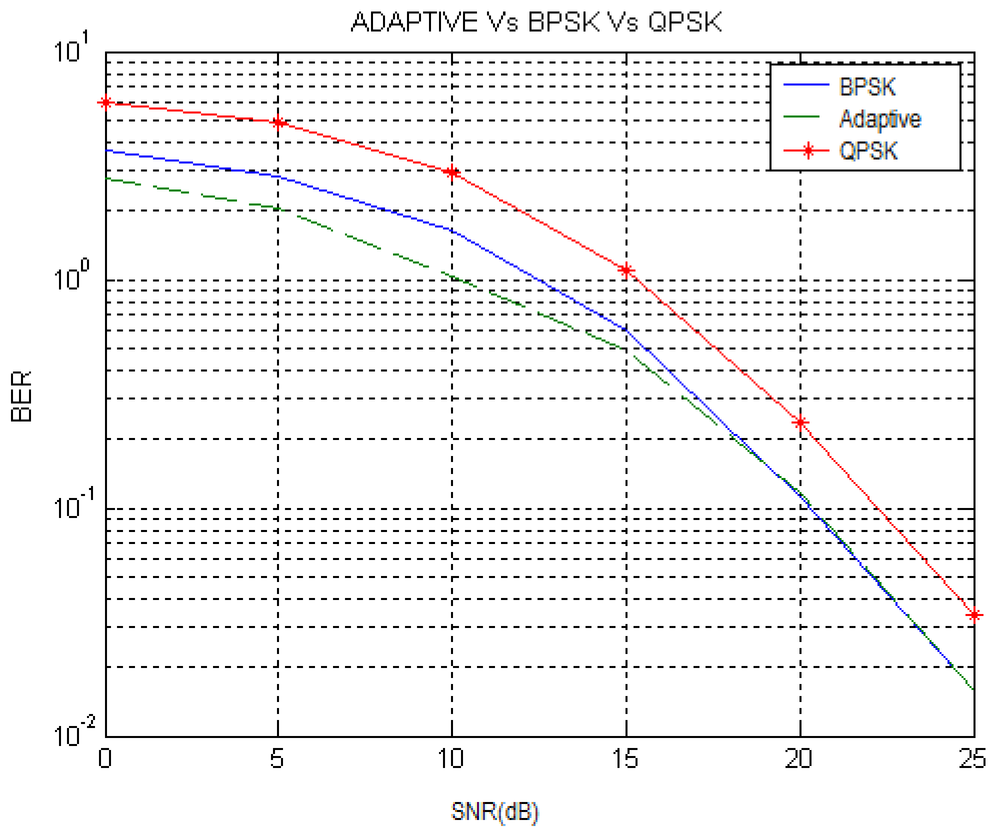

Figure 6.4 Adaptive SFBC-OFDM Vs BPSK vs. QPSK.

Figure 6.5 compares the performance of an adaptive modulated SFBC-OFDM system with antenna selection (2Tx-3Tx) and an adaptive modulated SFBC-OFDM system. As shown, at a low SNR the adaptive system without antenna selection is better than adaptive system with antenna selection, but at a high SNR, the adaptive system with antenna selection has a dramatic improvement of more than 4 dB.

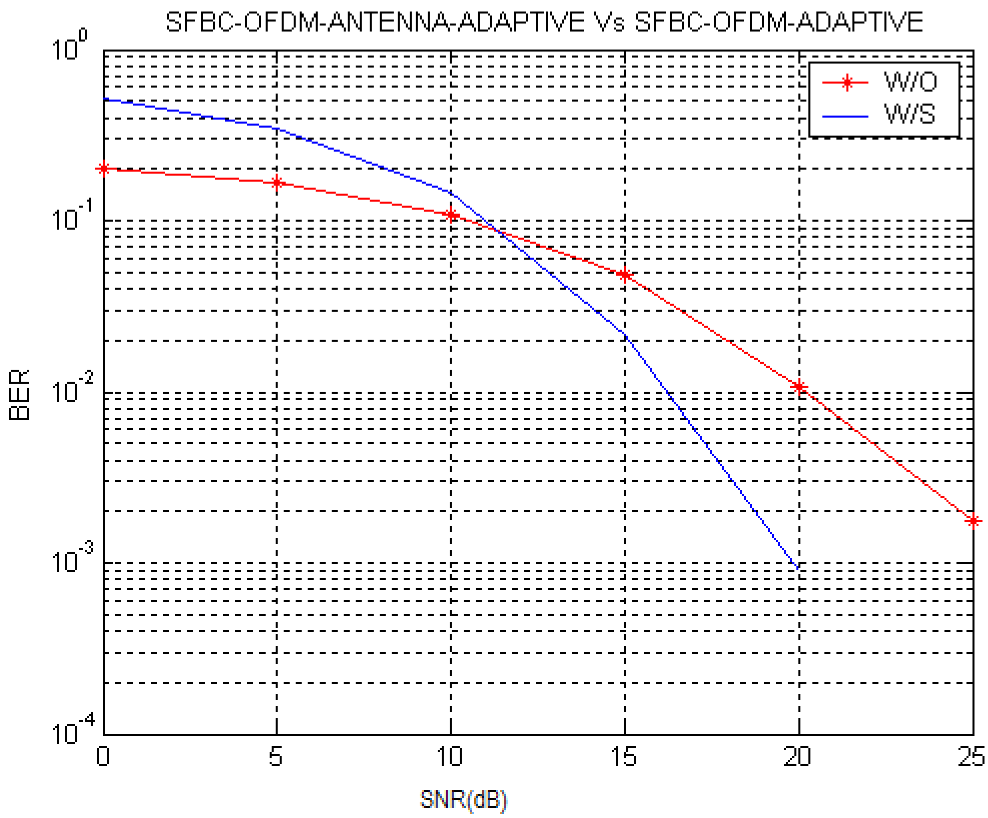

Figure 6.5 Adaptive -SFBC-OFDM with antenna selection (2 Tx-3Tx) vs. adaptive SFBC-OFDM

CHAPTER 7

CONCLUSION

In this thesis, a new antenna selection scheme was presented along with conventional SFBC-OFDM systems. The antenna selection scheme considered the selection of Y_T transmitter antennas (based on best antenna selection at each frequency) out of X_T given antennas and a single receiver antenna. This system combined with SFBC-OFDM along with adaptive modulation was simulated under Rayleigh fading channels. The coding gain improvement for unequal power distribution was shown. This unequal power distribution combined with the proposed antenna selection scheme greatly improves the performance of the system. The coding and diversity gain advantages were examined. It was shown that the proposed system greatly improves the performance of the conventional SFBC-OFDM systems. This thesis deals only with multiple transmitter antennas and a single receive antenna. This can be extended to multiple antennas at receiver as well. BPSK and QPSK are used in this thesis for simplicity. These can be extended to higher modulations.

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APPENDICES

APPENDIX A

SFBC with OFDM (BPSK)

```
clear all;
clc;
%*****************************************************
SNRdb=0:5:25;
for s=1:length(SNRdb)
 snr(s)=10.^(SNRdb(s)/10);
sigma(s)=1./(2*snr(s));
toterr=0;
Ns=16;
Fr=(Ns*10000)/Ns;
for z=1:Fr   % for 1000 OFDM symbols namely 256000 bits
%************************  TRANSMITTER  ***************************
%************************  TRANSMITTER  ***************************
data1= randsrc(1,Ns); % BPSK modulation; -1 and +1
 data=sqrt(0.5)*data1;%ifft(data1);
for k=1:Ns/2
    d1(2*k-1)=data(2*k-1);
    d1(2*k)=-conj(data(2*k));
    d2(2*k-1)=data(2*k);
    d2(2*k)=conj(data(2*k-1));
    end;
```

```
sant1=ifft(d1);
sant2=ifft(d2);
% ********************** CHANNEL *********************
% ********************** CHANNEL *********************
h1=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));
 h2=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));
y=sant1.*h1+sant2.*h2;
 noise=sqrt(sigma(s))*(randn(1,Ns)+sqrt(-1)*randn(1,Ns));
 rcvd1=y+noise;
 rcvd=fft(rcvd1);
 %%%%%%%STBC decoder %%%%%%%(2*k)
 for k=1:Ns/2
     dcap(2*k-1)=rcvd(2*k-1)*conj(h1)+conj(rcvd(2*k))*h2;
     dcap(2*k)=rcvd(2*k-1)*conj(h2)-conj(rcvd(2*k))*h1;
 end;
 dcapf=(dcap);
  dec=sign(real(dcapf));
 errf=length(find(dec-data1));
 toterr=toterr+errf;
end; %end of z
err(s)=toterr
end % end of s
semilogy(SNRdb,err/(Ns*Fr),'r'),grid on
```

```
hold on;

title('Performance of STBC with OFDM');

grid;

% %***************** THE END ************************

% %***************** THE END ************************
```

APPENDIX B

SFBC with OFDM (QPSK)

```
clear all;
clc;
%**************************************************
 SNRdb=0:5:25;
 for s=1:length(SNRdb)
 snr(s)=10.^(SNRdb(s)/10);
sigma(s)=1./(2*snr(s));
toterr=0;
Ns=16;
Fr=(Ns*10000)/Ns;
for z=1:Fr   % for 1000 OFDM symbols namely 256000 bits
%*********************** TRANSMITTER ***************************
%*********************** TRANSMITTER ***************************
data1= complex(randsrc(1,Ns),randsrc(1,Ns)); % QPSK modulation; -1 and +1
 data=sqrt(0.5)*data1;%ifft(data1);
for k=1:Ns/2
    d1(2*k-1)=data(2*k-1);
    d1(2*k)=-conj(data(2*k));
    d2(2*k-1)=data(2*k);
    d2(2*k)=conj(data(2*k-1));
```

```
    end;
sant1=ifft(d1);
sant2=ifft(d2);
% ********************** CHANNEL *********************
% ********************** CHANNEL *********************
h1=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));
 h2=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));
  y=sant1.*h1+sant2.*h2;
 noise=sqrt(sigma(s))*(randn(1,Ns)+sqrt(-1)*randn(1,Ns));
 rcvd1=y+noise;
 rcvd=fft(rcvd1);
 %%%%%%%STBC decoder %%%%%%%(2*k)
 for k=1:Ns/2
     dcap(2*k-1)=rcvd(2*k-1)*conj(h1)+conj(rcvd(2*k))*h2;
     dcap(2*k)=rcvd(2*k-1)*conj(h2)-conj(rcvd(2*k))*h1;
 end;
 dcapf=(dcap);
 decR=sign(real(dcapf));
 decI=sign(imag(dcapf));
 dec=complex(decR,decI);
 errf=length(find(dec-data1));
 toterr=toterr+errf;
end; %end of z
```

```
err(s)=toterr

end % end of s

hold on;

semilogy(SNRdb,err/(Ns*Fr)),grid on

 % %***************** THE END ************************

% %***************** THE END ************************
```

APPENDIX C

SFBC with OFDM (UNEQUAL POWER DISTRIBUTION)

```
clear all;
clc;
%****************************************************
 SNRdb=0:5:25;
 for s=1:length(SNRdb)
 snr(s)=10.^(SNRdb(s)/10);
sigma(s)=1./(2*snr(s));
toterr=0;
Ns=16;
Fr=(Ns*10000)/Ns;
for z=1:Fr   % for 1000 OFDM symbols namely 256000 bits
%************************ TRANSMITTER ***************************
%************************ TRANSMITTER ***************************
h1=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));
h2=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));
data1= complex(randsrc(1,Ns),randsrc(1,Ns)); % QPSK modulation;
 data=data1;%ifft(data1);
% STBC encoder
 for k=1:Ns/2
    d1(2*k-1)=data(2*k-1);
```

```
    d1(2*k)=-conj(data(2*k));
    d2(2*k-1)=data(2*k);
    d2(2*k)=conj(data(2*k-1));
    end;
sant1=ifft(sqrt(0.7)*d1);
sant2=ifft(sqrt(0.3)*d2);
% ********************** CHANNEL *********************
% ********************** CHANNEL *********************
% Ns=256;
y=sant1.*h1+sant2.*h2;
 noise=sqrt(sigma(s))*(randn(1,Ns)+sqrt(-1)*randn(1,Ns));
  rcvd1=y+noise;
 rcvd=fft(rcvd1);
 %%%%%%%STBC decoder %%%%%%%(2*k)
 for k=1:Ns/2
     dcap(2*k-1)=rcvd(2*k-1)*conj(h1)+conj(rcvd(2*k))*h2;
     dcap(2*k)=rcvd(2*k-1)*conj(h2)-conj(rcvd(2*k))*h1;
 end;
 dcapf=(dcap);
  decR=sign(real(dcapf));
 decI=sign(imag(dcapf));
 dec=complex(decR,decI);
 errf=length(find(dec-data1));
```

```
 toterr=toterr+errf;
 end; %end of z
err(s)=toterr
end % end of s
hold on;
semilogy(SNRdb,err/(Ns*Fr),'-*r'),grid on
 % %***************** THE END ************************
% %***************** THE END ************************
```

APPENDIX D

SFBC – OFDM WITH ANTENNA SELECTION (BPSK)

```
clear all;
clc;
%***************************************************
SNRdb=0:5:25;
 for s=1:length(SNRdb)
 snr(s)=10.^(SNRdb(s)/10);
sigma(s)=1./(2*snr(s));
toterr=0;
Ns=16;
Fr=(Ns*10000)/Ns;
for z=1:Fr   % for 1000 OFDM symbols namely 256000 bits
%************************  TRANSMITTER  ***************************
%************************  TRANSMITTER  ***************************
h1=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));
h2=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));
h3=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));
 h4=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));
 H=0;
if h1>h2
    H=h1;
```

```
else
   H=h2;
end
 H1=0;
if H>h3
   H1=H;
else
   H1=h3;
End
H2=0;
if H1>h4
   H2=H1;
else
   H2=h4;
end
data1= randsrc(1,Ns); % BPSK modulation; -1 and +1
 data=sqrt(0.5)*data1;%ifft(data1);
for k=1:Ns/2
    d1(2*k-1)=data(2*k-1);
    d1(2*k)=-conj(data(2*k));
    d2(2*k-1)=data(2*k);
    d2(2*k)=conj(data(2*k-1));
    end;
```

```
sant1=ifft(d1);
sant2=ifft(d2);
% ********************** CHANNEL *********************
% ********************** CHANNEL *********************
h1=H2;
h2=H2;
 y=sant1.*h1+sant2.*h2;
noise=sqrt(sigma(s))*(randn(1,Ns)+sqrt(-1)*randn(1,Ns));
 rcvd1=y+noise;
  rcvd=fft(rcvd1);
 %%%%%%STBC decoder %%%%%%%(2*k)
 for k=1:Ns/2
     dcap(2*k-1)=rcvd(2*k-1)*conj(h1)+conj(rcvd(2*k))*h2;
     dcap(2*k)=rcvd(2*k-1)*conj(h2)-conj(rcvd(2*k))*h1;
 end;
 dcapf=(dcap);
 dec=sign(real(dcapf));
errf=length(find(dec-data1));
 toterr=toterr+errf;
end; %end of z
err(s)=toterr
end % end of s
semilogy(SNRdb,err/(Ns*Fr),'-*r'),grid on
```

```
hold on;

% %****************** THE END *************************

% %****************** THE END *************************
```

APPENDIX E

SFBC – OFDM WITH ANTENNA SELECTION (QPSK)

```
clear all;

clc;

%*************************************************

SNRdb=0:5:25;

 for s=1:length(SNRdb)

 snr(s)=10.^(SNRdb(s)/10);

sigma(s)=1./(2*snr(s));

toterr=0;

Ns=16;

Fr=(Ns*10000)/Ns;

for z=1:Fr   % for 1000 OFDM symbols namely 256000 bits

%*********************** TRANSMITTER ***************************

%*********************** TRANSMITTER ***************************

h1=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));

 h2=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));

h3=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));

 h4=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));

 H=0;

if h1>h2

    H=h1;
```

```
else
   H=h2;
end
 H1=0;
if H>h3
   H1=H;
else
   H1=h3;
End
 H2=0;
if H1>h4
   H2=H1;
else
   H2=h4;
end
data1= complex(randsrc(1,Ns),randsrc(1,Ns)); % QPSK modulation; -1 and +1
 data=sqrt(0.5)*data1;%ifft(data1);
for k=1:Ns/2
   d1(2*k-1)=data(2*k-1);
   d1(2*k)=-conj(data(2*k));
   d2(2*k-1)=data(2*k);
   d2(2*k)=conj(data(2*k-1));
   end;
```

```
sant1=ifft(d1);
sant2=ifft(d2);
% ********************** CHANNEL *********************
% ********************** CHANNEL *********************
h1=H2;
h2=H2;
 y=sant1.*h1+sant2.*h2;
noise=sqrt(sigma(s))*(randn(1,Ns)+sqrt(-1)*randn(1,Ns));
  rcvd1=y+noise;
  rcvd=fft(rcvd1);
 %%%%%%%STBC decoder %%%%%%%(2*k)
 for k=1:Ns/2
     dcap(2*k-1)=rcvd(2*k-1)*conj(h1)+conj(rcvd(2*k))*h2;
     dcap(2*k)=rcvd(2*k-1)*conj(h2)-conj(rcvd(2*k))*h1;
 end;
 dcapf=(dcap);
 decR=sign(real(dcapf));
 decI=sign(imag(dcapf));
 dec=complex(decR,decI);
 errf=length(find(dec-data1));
 toterr=toterr+errf;
end; %end of z
err(s)=toterr
```

```
end % end of s

semilogy(SNRdb,err/(Ns*Fr),'-*r'),grid on

 hold on;

% %***************** THE END ************************
```

% %***************** THE END ************************

APPENDIX F

ADAPTIVE SFBC - OFDM

```
clear all;
clc;
%*****************************************************
SNRdb=0:5:25;
 for s=1:length(SNRdb)
 Ns=16;
snr(s)=10.^(SNRdb(s)/10);
sigma(s)=1./(2*snr(s));
toterrq=0;toterrb=0;
Fr=(Ns*10000)/Ns;
for z=1:Fr   % for 1000 OFDM symbols namely 256000 bits
%************************  TRANSMITTER  ***************************
%************************  TRANSMITTER  ***************************
 bits=round(rand(1,Ns)); %generate random 0,1 sequence
symbs =(-1).^bits;
h1=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));
  h2=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));
if h1>0.6 && h2>0.6
      q=4
    for i=1:length(bits)/2
```

```
     a=bits(2*i-1);
    b=bits(2*i);
    if (a==0 & b==0)
        AB(i)=1 ;
        elseif (a==1 & b==0)
       AB(i)=j;
        elseif (a==0 & b==1)
        AB(i)=-1;
         elseif (a==1 & b==1)
 AB(i)=-j;
end;
end;
dataq=sqrt(0.5)*AB;
else
  q=2
 datab=sqrt(0.5)*symbs;
end
if h1>0.6 && h2>0.6
for k=1:Ns/4
    d1q(2*k-1)=dataq(2*k-1);
    d1q(2*k)=-conj(dataq(2*k));
    d2q(2*k-1)=dataq(2*k);
    d2q(2*k)=conj(dataq(2*k-1));
```

```
    end;
sant1q=ifft(d1q);
sant2q=ifft(d2q);
else
    for k=1:Ns/2
    d1b(2*k-1)=datab(2*k-1);
    d1b(2*k)=-conj(datab(2*k));
    d2b(2*k-1)=datab(2*k);
    d2b(2*k)=conj(datab(2*k-1));
    end;
sant1b=ifft(d1b);
sant2b=ifft(d2b);
end;
% ********************** CHANNEL *********************
% ********************** CHANNEL *********************
 noiseb=sqrt(sigma(s))*(randn(1,Ns)+sqrt(-1)*randn(1,Ns));
 noiseq=sqrt(sigma(s))*(randn(1,Ns/2)+sqrt(-1)*randn(1,Ns/2));
 if h1>0.6 && h2>0.6
yq=sant1q.*h1+sant2q.*h2;
 rcvd1q=yq+noiseq;
 rcvdq=fft(rcvd1q);
else
 yb=sant1b.*h1+sant2b.*h2;
```

```
 rcvd1b=yb+noiseb;
 rcvdb=fft(rcvd1b);
end
 %%%%%%%STBC decoder %%%%%%%(2*k)
 if h1>0.6 && h2>0.6
 for k=1:Ns/4
     dcap(2*k-1)=rcvdq(2*k-1)*conj(h1)+conj(rcvdq(2*k))*h2;
     dcap(2*k)=rcvdq(2*k-1)*conj(h2)-conj(rcvdq(2*k))*h1;
 end;
else
    for k=1:Ns/2
     dcap(2*k-1)=rcvdb(2*k-1)*conj(h1)+conj(rcvdb(2*k))*h2;
     dcap(2*k)=rcvdb(2*k-1)*conj(h2)-conj(rcvdb(2*k))*h1;
 end;
end
  dcapf=(dcap);
 if h1>0.6 && h2>0.6
     for i=1:Ns/2,
  %   %maximum likelihood decision
ml1=abs((dcapf(i)-1).^2);
ml2=abs((dcapf(i)-j).^2);
ml3=abs((dcapf(i)+1).^2);
ml4=abs((dcapf(i)+j).^2);
```

```
ml=[ml1 ml2 ml3 ml4];
[val pos]=min(ml);
if(pos==1) ,dec1(i)=1;%00
elseif (pos==2), dec1(i)=j;  %10
elseif (pos==3), dec1(i)=-1;  %01
elseif (pos==4) dec1(i)=-j;             %11
end
end;
 err1q=length(find(dec1-AB));
toterrq=toterrq+err1q;
else
 dec3=sign(real(dcapf));
errf=length(find(dec3-symbs));
  toterrb=toterrb+errf;
end;
end; %end of z
if h1>0.6 && h2>0.6
errq(s)=2*toterrq
err(s)=errq(s);
else
errb(s)=toterrb
err(s)=errb(s);
end;
```

```
end; % end of s

semilogy(SNRdb,err/(Ns*Fr),'-*r'),grid on

hold on;
```

APPENDIX G

ADAPTIVE SFBC – OFDM WITH ANTENNA SELECTION

```
clear all;
clc;
%****************************************************
SNRdb=0:5:25;
 for s=1:length(SNRdb)
  Ns=16;
snr(s)=10.^(SNRdb(s)/10);
sigma(s)=1./(2*snr(s));
toterrq=0;toterrb=0;
Fr=(Ns*10000)/Ns;
for z=1:Fr   % for 1000 OFDM symbols namely 256000 bits
%***********************  TRANSMITTER  ***************************
%***********************  TRANSMITTER  ***************************
 bits=round(rand(1,Ns)); %generate random 0,1 sequence
symbs =(-1).^bits;
h11=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));
 h12=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));
h13=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));
  h14=abs(sqrt(0.5)*(randn(1,1)+sqrt(-1)*randn(1,1)));
 H=0;
```

```
if h11>h12
    H=h11;
else
    H=h12;
end
H1=0;
if H>h13
    H1=H;
Else
  H1=h13;
end
H2=0;
if H1>h14
    H2=H1;
else
    H2=h14;
end
h1=H2;
h2=H2;
if h1>0.6 && h2>0.6
      q=4
    for i=1:length(bits)/2
     a=bits(2*i-1);
```

```
    b=bits(2*i);
    if (a==0 & b==0)
        AB(i)=1 ;
        elseif (a==1 & b==0)
       AB(i)=j;
       elseif (a==0 & b==1)
        AB(i)=-1;
        elseif (a==1 & b==1)
       AB(i)=-j;
 end;
end;
dataq=sqrt(0.5)*AB;
else
 q=2
 datab=sqrt(0.5)*symbs;
end
if h1>0.6 && h2>0.6
for k=1:Ns/4
    d1q(2*k-1)=dataq(2*k-1);
    d1q(2*k)=-conj(dataq(2*k));
    d2q(2*k-1)=dataq(2*k);
    d2q(2*k)=conj(dataq(2*k-1));
end;
```

```
sant1q=ifft(d1q);
sant2q=ifft(d2q);
else
    for k=1:Ns/2
    d1b(2*k-1)=datab(2*k-1);
    d1b(2*k)=-conj(datab(2*k));
    d2b(2*k-1)=datab(2*k);
    d2b(2*k)=conj(datab(2*k-1));
    end;
 sant1b=ifft(d1b);
sant2b=ifft(d2b);
end;
% ********************** CHANNEL *********************
% ********************** CHANNEL *********************
 noiseb=sqrt(sigma(s))*(randn(1,Ns)+sqrt(-1)*randn(1,Ns));
 noiseq=sqrt(sigma(s))*(randn(1,Ns/2)+sqrt(-1)*randn(1,Ns/2));
 if h1>0.6 && h2>0.6
yq=sant1q.*h1+sant2q.*h2;
 rcvd1q=yq+noiseq;
 rcvdq=fft(rcvd1q);
else
 yb=sant1b.*h1+sant2b.*h2;
 rcvd1b=yb+noiseb;
```

```
 rcvdb=fft(rcvd1b);
end
 %%%%%%%STBC decoder %%%%%%%(2*k)
 if h1>0.6 && h2>0.6
 for k=1:Ns/4
     dcap(2*k-1)=rcvdq(2*k-1)*conj(h1)+conj(rcvdq(2*k))*h2;
     dcap(2*k)=rcvdq(2*k-1)*conj(h2)-conj(rcvdq(2*k))*h1;
 end;
else
    for k=1:Ns/2
     dcap(2*k-1)=rcvdb(2*k-1)*conj(h1)+conj(rcvdb(2*k))*h2;
     dcap(2*k)=rcvdb(2*k-1)*conj(h2)-conj(rcvdb(2*k))*h1;
 end;
end
  dcapf=(dcap);
 if h1>0.6 && h2>0.6
     for i=1:Ns/2,
  %   %maximum likelihood decision
ml1=abs((dcapf(i)-1).^2);
ml2=abs((dcapf(i)-j).^2);
ml3=abs((dcapf(i)+1).^2);
ml4=abs((dcapf(i)+j).^2);
ml=[ml1 ml2 ml3 ml4];
```

```
[val pos]=min(ml);
if(pos==1) ,dec1(i)=1;%00
elseif (pos==2), dec1(i)=j;  %10
elseif (pos==3), dec1(i)=-1;  %01
elseif (pos==4) dec1(i)=-j;     %11
end
end;
 err1q=length(find(dec1-AB));
toterrq=toterrq+err1q;
else
dec3=sign(real(dcapf));
errf=length(find(dec3-symbs));
 toterrb=toterrb+errf;
end;
end; %end of z
if h1>0.6 && h2>0.6
errq(s)=2*toterrq
err(s)=errq(s);
else
errb(s)=toterrb
err(s)=errb(s);
semilogy(SNRdb,err/(Ns*Fr),'-*r'),grid on
hold on;
```

```
end;

end; % end of s

semilogy(SNRdb,err/(Ns*Fr)),grid on
```