Design, Simulation and Performance Evaluation of 4 x 4 MIMO Transceiver System using 16 QAM

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ABSTRACT

The frequency spectrum has become scarce and an expensive resource limiting the bandwidth. The future systems need to be characterized by significantly enhanced spectral efficiency in order to increase link throughput and network capacity. In order to achieve high throughput and network capacity the best approach for real time application would be combining MIMO wireless technology with OFDM for next generation wireless local area networks. In the current paper a high level Matlab Simulink 4 x 4 spatially multiplexed MIMO OFDM transceiver encoded at ½ rate using 64 size FFT is designed and implemented.

General Terms

Orthogonal Frequency Division Multiplexing, Multiple Input Multiple Output, Wireless Local Area Network.

Keywords

Space Time Block Code, Spatial Multiplexing, Matlab Simulink.

1. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier-based technique for mitigating ISI to improve capacity in the wireless system with spectral efficiency. Multiple-Input Multiple-Output (MIMO) systems have achieved attention as it promises to increase capacity and performance with acceptable BER proportionally with the number of antennas. MIMO uses multiple antennas at both transmitter and receiver sides. The signals transmitted travel in space gets reflected by objects and received by receiver over the multiple paths. MIMO takes advantage of multipath by multiplexing those signals with advanced DSP algorithms to boost wireless bandwidth efficiency and range [3]. Hence combination of MIMO-OFDM is beneficial.

The MIMO OFDM system comprises of transmitter and receiver sections. The transmitter comprises blocks such as convolutional encoder, mapper, parser, and IFFT. The data encoded at a specific rate like ½ or 2/3 and then is modulated using BPSK/ QPSK/QAM modulation [7]. This signal is then parsed into two or more channels and later it is converted into time domain and transmitted. The operation of receiver blocks is opposite to that of transmitter to receive the actual signal.
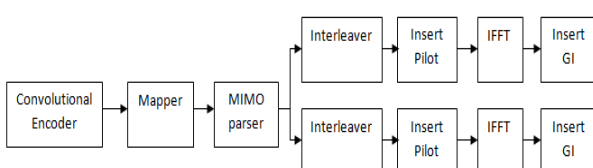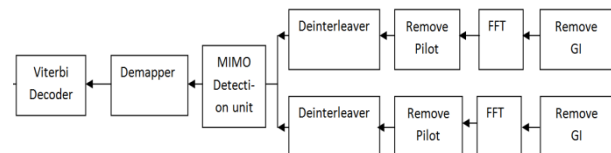

Fig1.1 MIMO OFDM Transmitter Block diagram

Fig.1.2 MIMO OFDM Receiver Block diagram

The paper is organized in the order mentioned as follows: The Section 2 describes about MIMO and MIMO based techniques such as STBC (Space Time Block Code) and SM (Spatial Multiplexing). The capacity of different systems like SISO, SIMO, MISO and MIMO are compared. Section 3 describes the implementation of 4 x 4 MIMO system using Matlab Simulink and Xilinx software. In Section 4 factors affecting data rate and complexity of the system are discussed. The Section 5 describes about results and conclusions.

2. MIMO

In MIMO system multiple antennas are employed at the transmitter and the receiver. MIMO transmits and receives two or more data streams through a single radio channel. Thereby the system can deliver two or more times the data rate per channel without additional bandwidth or transmit power [1].The addition of multiple antennas at the transmitter combined with advanced digital signal processing based algorithms and the receiver yields significant advantage in terms of capacity and diversity [10].

Space-time block coding and spatial multiplexing are MIMO based techniques that provide link quality and high capacity in the system. STBC and SM can be combined to give a transmission scheme that will maximize the average data rate over the MIMO channel and guarantee a minimum order of diversity benefit for each stream [13].

The SIMO 1 x 4 system provides lower capacity than MIMO 2 x 2 system while still higher capacity is achieved in case of 4 x 4 MIMO system [12]. Therefore the capacity of system increases linearly with increased number of antennas.

For a memory less SISO system the capacity is given by
$$C = \log_2\left(1 + \rho|h^2|\right) \quad \text{b/s/Hz} \quad (1)$$

Where h is the normalized complex gain of a fixed wireless, ρ is the SNR at any Receiver antenna.

The capacity for a SIMO system is given by
$$C = \log_2\left(1 + \rho \sum_{i=1}^{M} |h_i|^2\right) \quad \text{b/s/Hz} \quad (2)$$

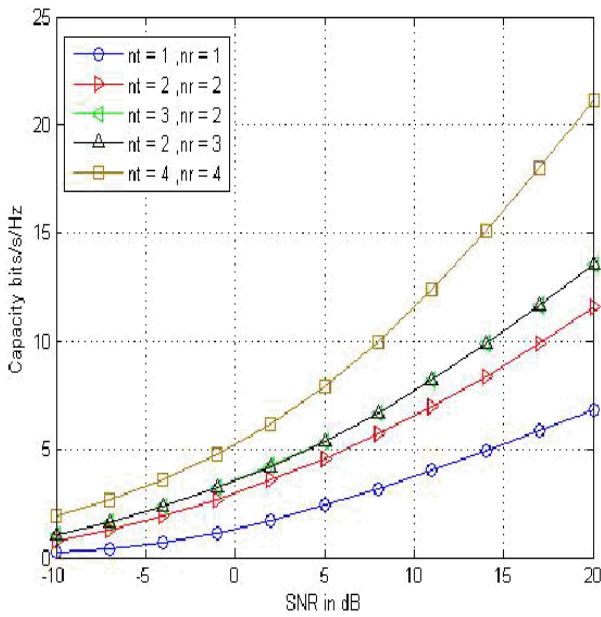Where h_i is the gain for receiver antenna i.

Fig 2: Capacity Performance

The capacity for a multiple input–single-output MISO system with N transmitter antennas is given by

$$C = \log_2\left(1 + \frac{\rho}{N}\sum_{i=1}^{N}|h_i|^2\right) b/s/Hz \qquad (3)$$

The capacity for a MIMO system with N Transmitter and M Receiver antennas is given by

$$C = \log_2\left[\det\left(I_M + \frac{\rho}{N}HH^*\right)\right] b/s/Hz \qquad (4)$$

Where (∗) means transpose-conjugate and H is the M x N channel matrix.

2.1 Space-Time Block Coding

Space-Time Block Coding (STBC) is a scheme in which the information is transmitted simultaneously on different antennas. Alamouti proposed an orthogonal block code using two transmitters and two receiver (N × M = 2 × 2). Every two time slots, two symbols are transmitted simultaneously over two antennas. At the first symbol time, s1 is transmitted from antenna 1, and s2 from antenna 2. Next, -s2 * is transmitted from antenna 1, and s1* from antenna 2 at the second symbol time [5]. The code has full diversity as the same information is transmitted over independent paths to mitigate fading. Using simple linear combining, the transmitted signal can be decoded. The very simple structure and linear processing of the Alamouti construction makes it very attractive scheme.
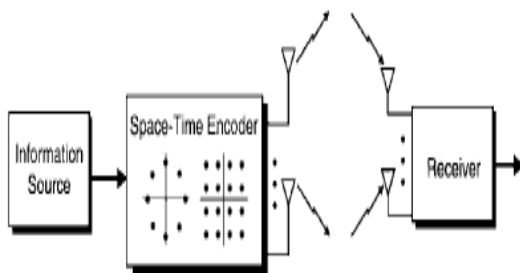

Fig2.1.1:Space-Time Block Coding.

2.2 Spatial Multiplexing

The concept of spatial multiplexing (SM) is different from that of space-time block coding method. The spatial multiplexing method uses multiple antennas at the transmitter and receiver to provide a linearly increasing capacity gain with increased number of antennas. In this system a high rate bit stream is decomposed into four independent 1/3 rate bit sequences which are then transmitted using multiple antennas. These signals get mixed in the channel as they use same frequency spectrum. At the receiver individual bit streams are separated, estimated and merged together to yield the original signal.

The input output relation for N transmitter antennas and M receiver antennas MIMO system is given by

$$y = H x + n \qquad (5)$$

Where $x = [x_1, x_2, \ldots x_N]^T$ is the N x 1vector of transmitted symbols, y, n are the M x 1 vectors of received symbols and noise respectively and H is the M x N matrix of channel coefficients [13].
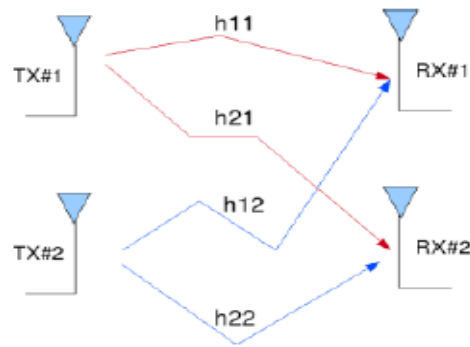

Fig 2.2.1: Illustration of MIMO channel

For a 2 x 2 MIMO channel
$$Y_1 = h_{11} x_1 + h_{12} x_2 + n_1 \qquad (6)$$
$$Y_2 = h_{21} x_1 + h_{22} x_2 + n_2 \qquad (7)$$

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \qquad (8)$$

For an N x M MIMO system the H matrix is given as

$$H = \begin{bmatrix} h_{11} & h_{12} h_{13} \cdots \cdots & h_{1N} \\ h_{21} & h_{22} h_{23} \cdots \cdots & h_{2N} \\ h_{31} & h_{32} h_{33} \cdots \cdots & h_{3N} \\ \vdots & \vdots \quad \vdots \quad \ddots & \vdots \\ h_{M1} h_{M2} h_{M3} & \cdots & h_{MN} \end{bmatrix} \qquad (9)$$

$$Y_1 = h_{11} x_1 + h_{12} x_2 + h_{13} x_3 + \ldots\ldots + h_{1N} x_{4} + n_1 \quad (10)$$
$$Y_2 = h_{21} x_1 + h_{22} x_2 + h_{23} x_3 + \ldots\ldots + h_{2N} x_4 + n_2 \qquad (11)$$
$$Y_3 = h_{31} x_1 + h_{32} x_2 + h_{33} x_3 + \ldots\ldots + h_{3N} x_4 + n_3 \qquad (12)$$
$$\vdots \quad \vdots \quad \vdots \quad \vdots \quad \vdots \quad \vdots$$
$$Y_M = h_{M1} x_1 + h_{M2} x_2 + h_{M3} x_3 + \ldots + h_{MN} x_N + n_M \quad (13)$$

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ \vdots \\ y_M \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} h_{13} \cdots \cdots & h_{1N} \\ h_{21} & h_{22} h_{23} \cdots \cdots & h_{2N} \\ h_{31} & h_{32} h_{33} \cdots \cdots & h_{3N} \\ \vdots & \vdots \quad \vdots \quad \ddots & \vdots \\ h_{M1} h_{M2} h_{M3} & \cdots & h_{MN} \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_N \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ \vdots \\ n_M \end{bmatrix} \qquad (14)$$
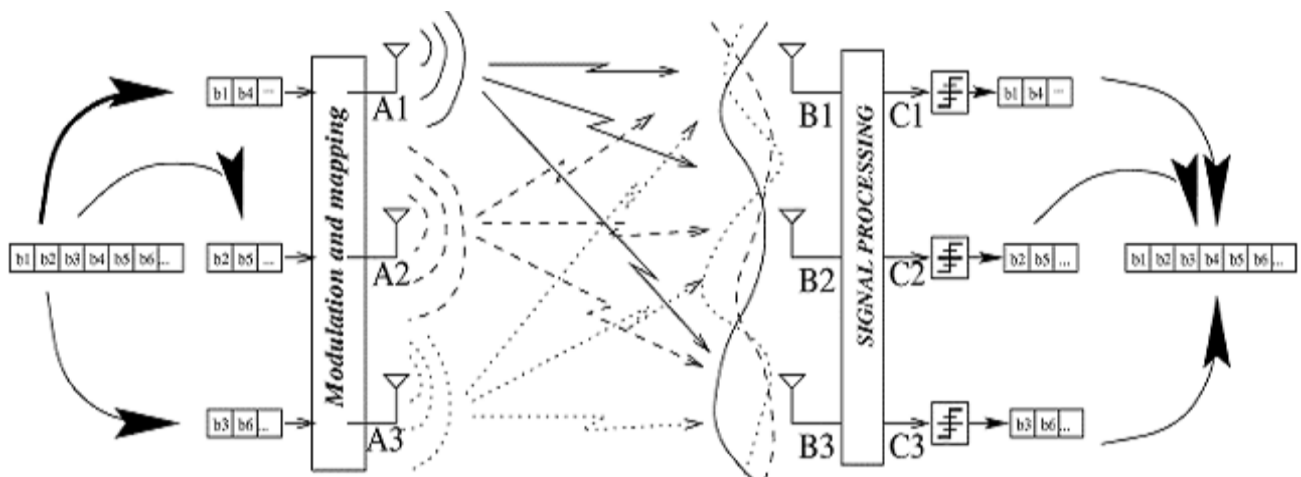
Fig 2.2.2: Spatial Multiplexing scheme

3. 4 x 4 MIMO System Description

The 4 x 4 MIMO model is illustrated in figure 3.1. The system is designed and implemented on a high level mathematical modeling of Matlab Simulink. The reason for selecting Matlab Simulink is because of its real time environment which resembles the real time design. The system is made of two important parts of transmitter and receiver. The next two subsections describe each part of the transceiver.

A real time audio signal is applied to the workspace with the help of a manual switch. The input sampled voice signal is then passed through the parallel to serial convertor and is given to the Subsystem. The subsystem is the transmitter module while subsystem 1 is the receiver module. The transmitter has various parts where the data bits are encoded using the convolutional encoder. The encoded bits then are punctured and mapped using one of the standard constellations. Next the bits are fed to the parser which split outs the single channel into four streams and then it is given at the receiver. The receiver functions in the reverse order as that of the transmitter by combining the four streams into one and de-mapping and decoding the bits to get the actual audio signal.

A scope is connected where the first plot is for output of 4 x 4 MIMO model whereas the second plot is just the input signal applied to the system to verify the same signal is reproduced at the receiver side. A SNR of 15 dB is added along with displays, scopes at different points to understand functioning of the entire system.

3.1 The Transmitter Subsystem

The transmitter mainly comprises of convolutional encoder, mapper, MIMO parser and IFFT. The sampled input voice bits are encoded using a ½ convolutional encoder, truncated, concated and is given to the mapper. The ROM_Imaginary (ROM_Imag), ROM_Real altogether forms QAM mapper. The ROM_Imag provides the value on imaginary axis while ROM_Real provides the value on real axis giving up the points on different quadrants.

MIMO Parser: The ROM-Imag and ROM_Real are fed to the MIMO parser as In 1 and In 2 respectively. The main purpose of using a MIMO parser is to split the single stream input into two streams.

Ofdm block: The first ROM_Imag and first ROM_Real i.e. the first and third outputs of MIMO parser1 are applied as inputs to the ofdm 1 block. A 64 size IFFT transforms the signal into time domain. The pilot and guard interval subcarriers are automatically inserted and the output is given at ofdm_out. The ofdm 2 block performs exactly same as that of ofdm 1 block and extracts the ROM_Imag and ROM_Real inputs for mimo deparser. The ofdm 3 and 4 performs exact same as that of ofdm 1 and 2 respectively to be fed as inputs for mimo deparser.

3.2 The Receiver Subsystem

In receiver subsystem outputs of four streams from transmitter are fed as input to ofdm blocks. In ofdm1 FFT performs the exact reverse operation as that of the IFFT. It will remove the pilot and guard subcarriers and extract the ROM_Imag and ROM_Real inputs for mimo deparser. The ofdm 2 block performs exactly same as that of ofdm 1 block and extracts the ROM_Imag and ROM_Real inputs for mimo deparser. The ofdm 3 and 4 performs exact same as that of ofdm 1 and 2 respectively to be fed as inputs for mimo deparser 1.
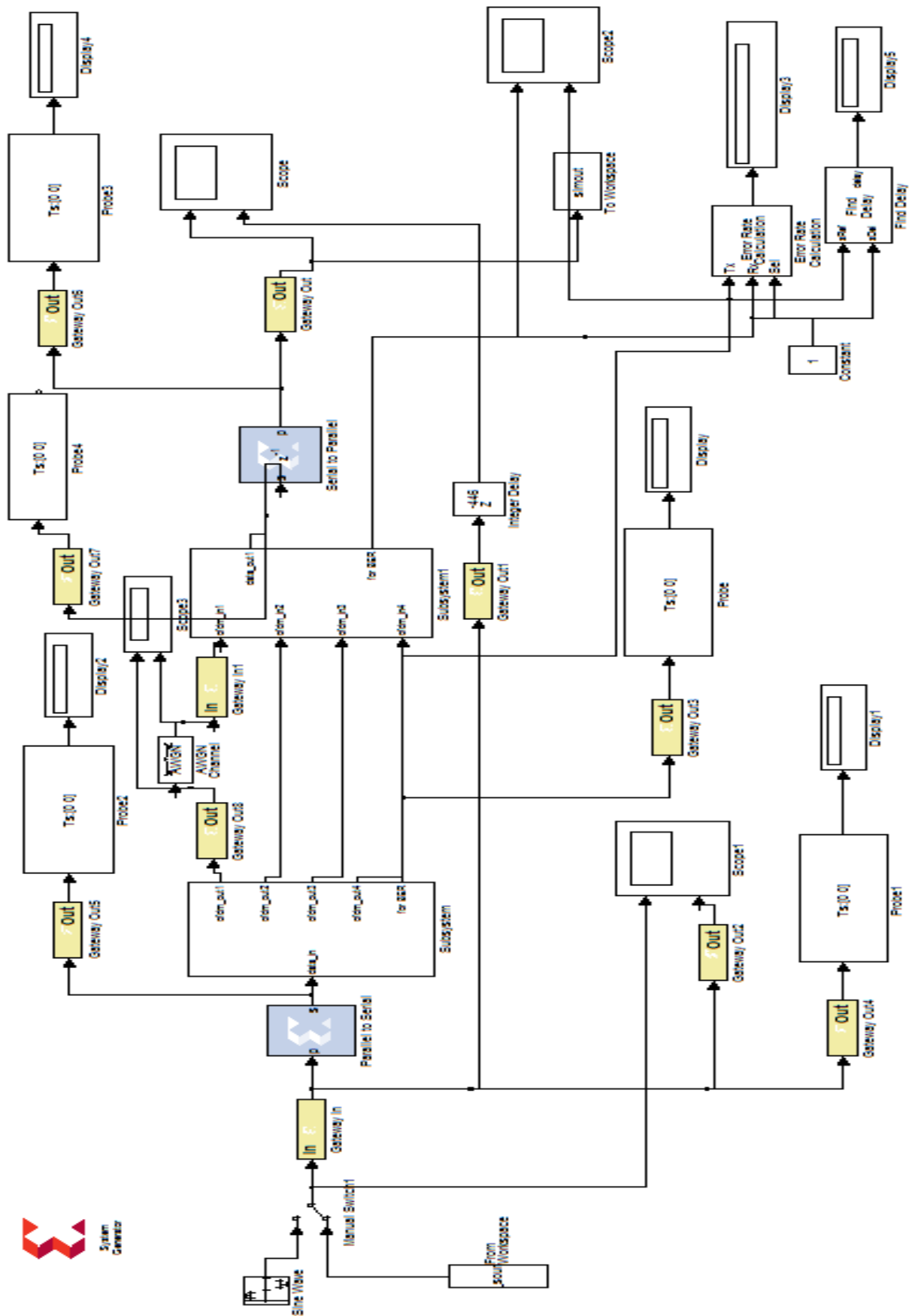
MIMO Deparser: At the transmitter side the signal is divided whereas at the receiver signals are being combined together. The combination of two or more signals is deparsing. The MIMO Deparser uses two Time Division Multiplexer. Two ROM_Imag signals are combined to form a single ROM_Real while the two ROM_Real signals are combined to form a single ROM_Imag signals. The output of mimo Deparser and mimo Deparser 1 are connected to mimo Deparser 2 so that the splitted streams can be combined together and ROM_Imag and ROM_Real signals can be obtained.

Demodulator and Decoder: The ROM_REAL and ROM_IMAG signals are fed as inputs X_r and X_i to the demodulator respectively. A Matlab code is used for QAM demodulator and is given out at D_{out}. The decoder which consists of serial to parallel block and a decoder block. A

Matlab code is written for the purpose of decoding the actual data. The first plot is for output of 4 x 4 MIMO model whereas the second plot is just the input signal applied to the system to verify the same signal is reproduced at the receiver side.
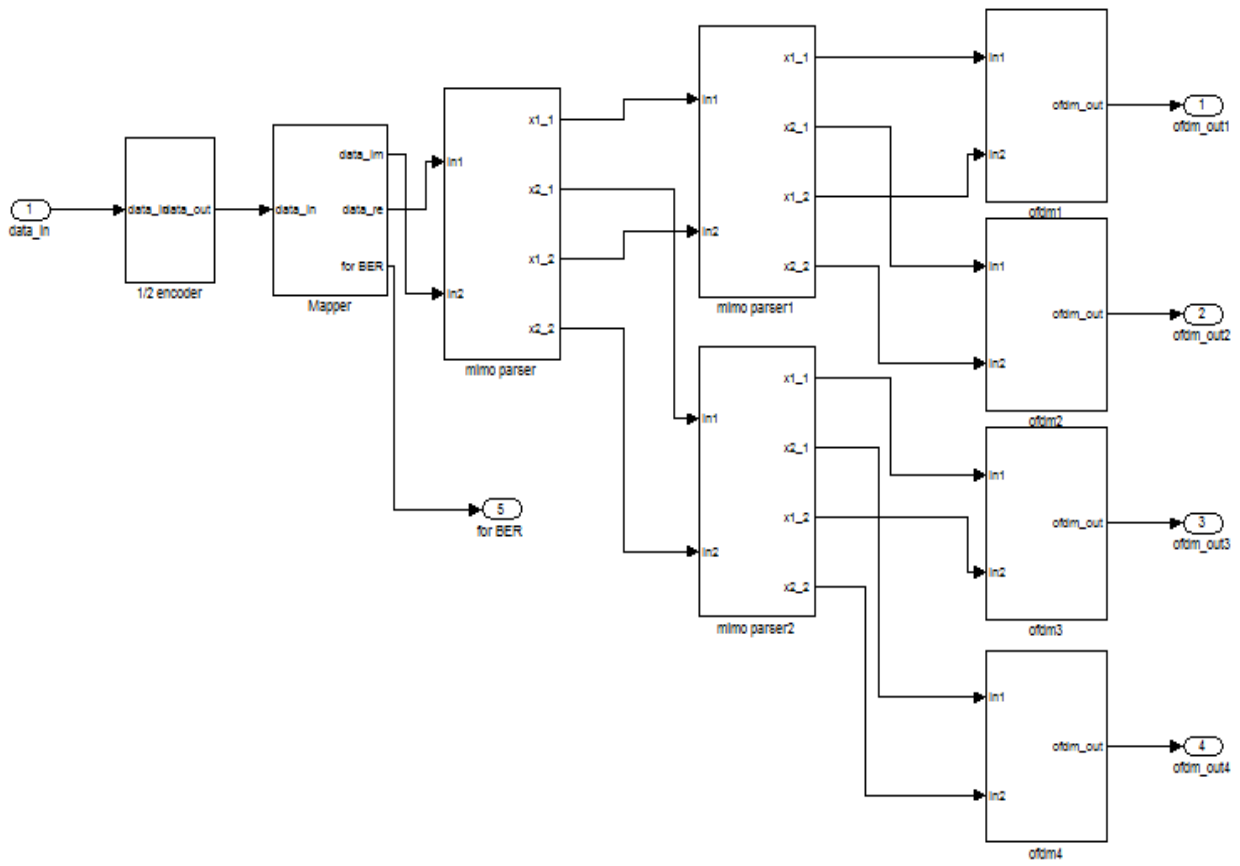
Fig 3.1. 4 x 4 MIMO model.
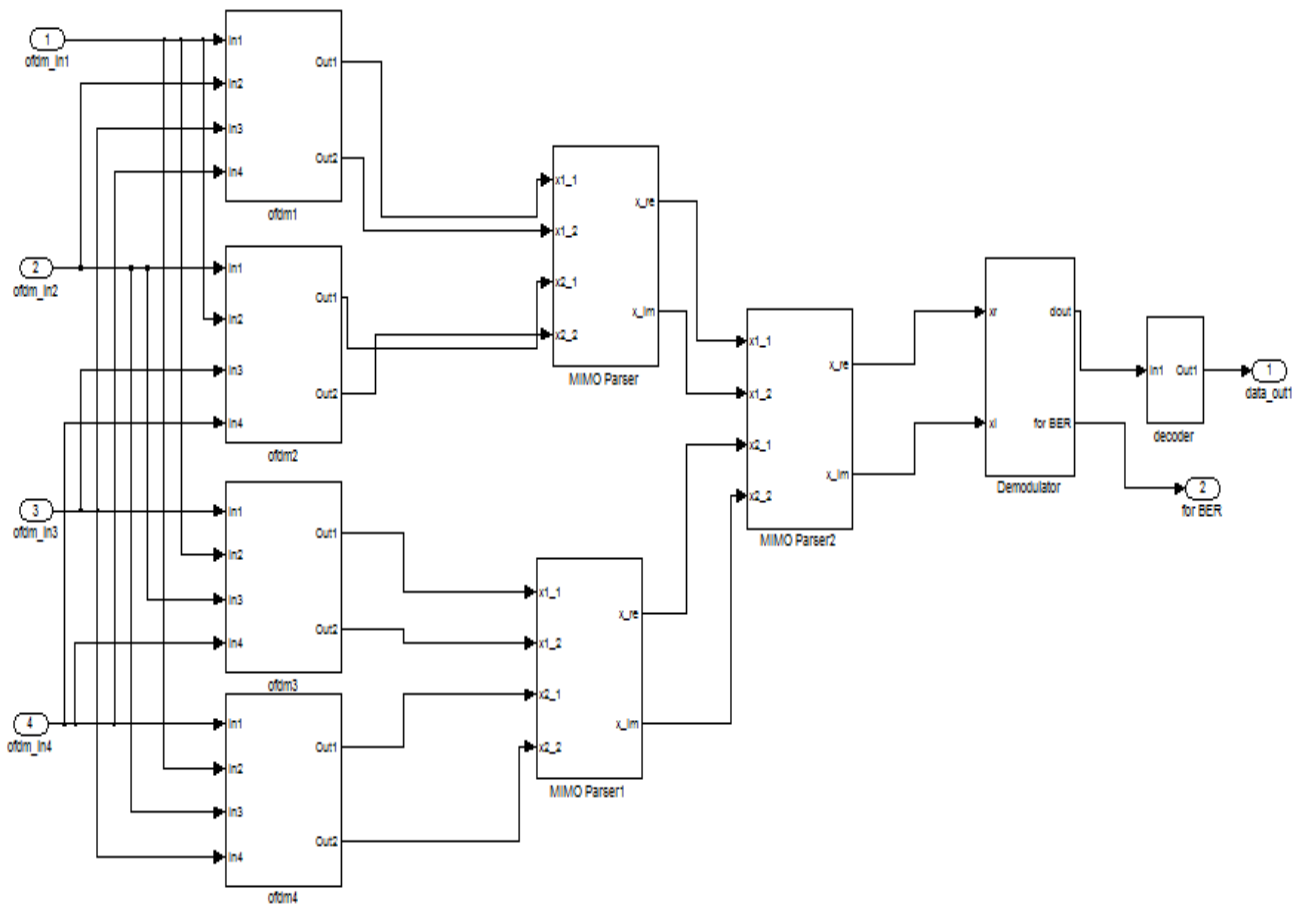
Fig 3.1.1 The Transmitter Module.

Fig 3.2.1 The Receiver Module

4. Reported Results and Discussion

The data rate in OFDM system depends on various factors such as the number of antennas used for transmission and reception of signals, the constellation, the DFT size, and the parsing method. A large FFT size could increase a transmit rate at a cost of increased complexity. STBC results best at low to medium values of SNR due to its robustness to poor channel conditions. SM results best at high values of SNR [12].

High data rates up to 216 Mbps can be achieved when more number of bits is transmitted per symbol. Thus when very high data rates are required, higher order QAM are used. However, the higher the number of bits per symbol, the more susceptible the scheme is to the Inter-Symbol Interference and noise [6].

At low SNRs STBC achieves high throughput than spatial multiplexing [2]. At higher SNR, spatial multiplexing performs better. Higher data rates for higher bandwidths can be achieved by using large DFT size [9]. For very high data rate requirements higher order QAM is used but it makes the scheme more susceptible to ISI.

In order to change the data rate Fs and Ts values is to be set. Fs and Ts are the sampling frequency and sample period at the input which appears at the Matlab Workspace as shown in figure 4.1.

Fig. 4.1 Fs and Ts values in Matlab Workspace

At the input, by default the sampling frequency is 4 K Hz and Sample period is Ts = 1/Fs. The data rate at the transmitter can be seen with the help of sample time block as shown in figure 4.2.
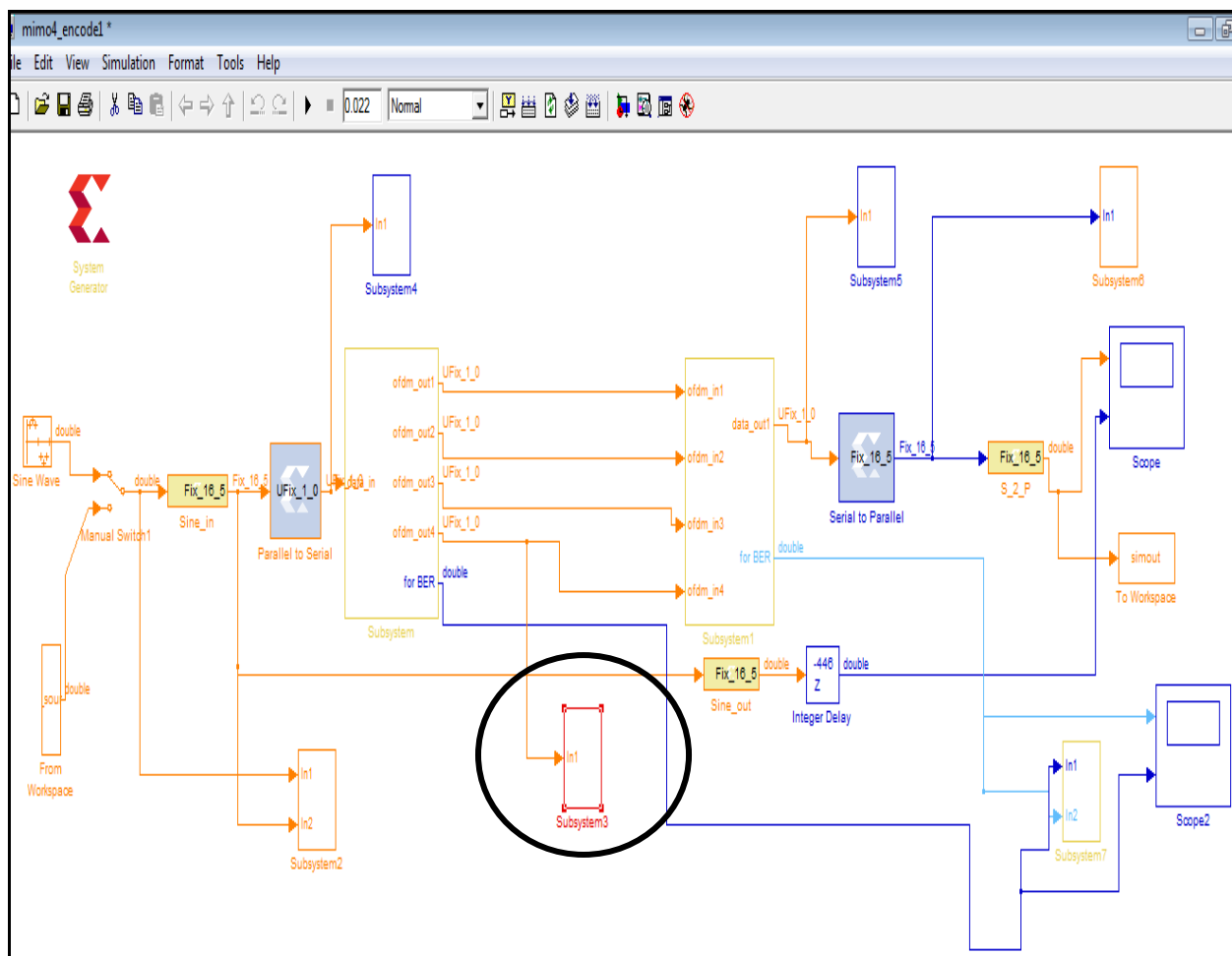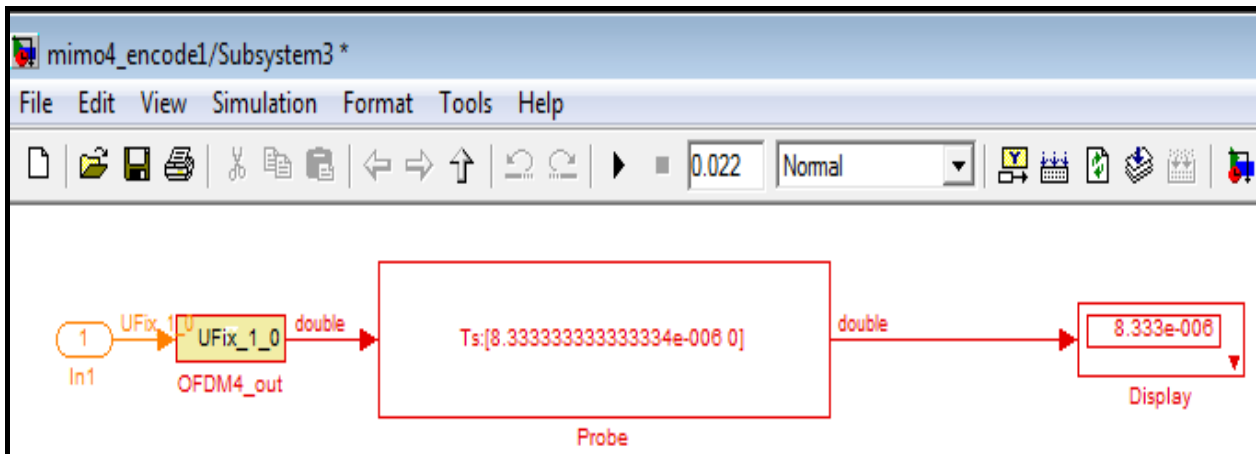

Fig. 4.2. Sample Time Block

Fig. 4.3. Ts display on probe in Sample Time Block

The sample time at the transmitter as shown in figure 4.3 is Ts = 8.333333334e-006. The sampling frequency at the transmitter is Fs = 1/Ts = 1/8.333334e-006 = 0.1 MHz i.e. 0.1Mbps. To change the Sampling frequency at the transmitter to 21 MHz, Fs = 700 KHz is to be set in the Matlab workspace and run the model as shown in figure 4.4.

21 MHz so, the data rate becomes 21Mbps. Similarly Fs can be changed to various frequencies and data rate can be achieved to 54 *4 = 216 Mbps. The list of Input sampling frequencies to change transmitter sampling frequencies and achieved data rates between 84 to 216 Mbps are as shown below.

Table I. Input Frequency and Data Rate

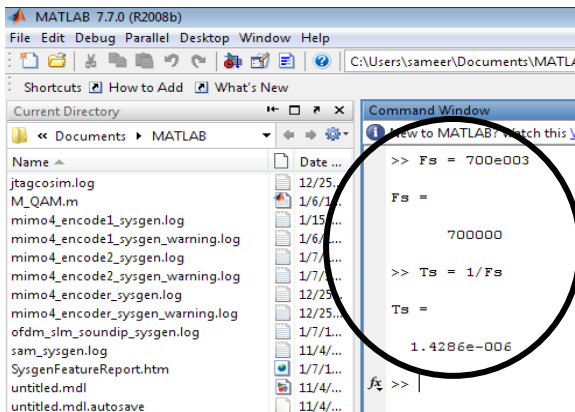| Sr. No.	Input Sampling Freq.	Transmitter Sampling Freq.	Data Rate
1	700 KHz	21 MHz	84 Mbps
2	840 KHz	25 MHz	100 Mbps
3	980 KHz	29 MHz	116 Mbps
4	1.120 MHz	33 MHz	132 Mbps
5	1.3 MHz	39 MHz	156 Mbps
6	1.5 MHz	45 MHz	135 Mbps
7	1.7 MHz	51 MHz	204 Mbps
8	1.8 MHz	54 MHz	216 Mbps

Fig. 4.4. Setting Fs and Ts values

The transmitter data rate can be probed by sample time block where Ts = 4.762e-008, Fs = 1/Ts = 1/4.762e-008 = 21e006 =
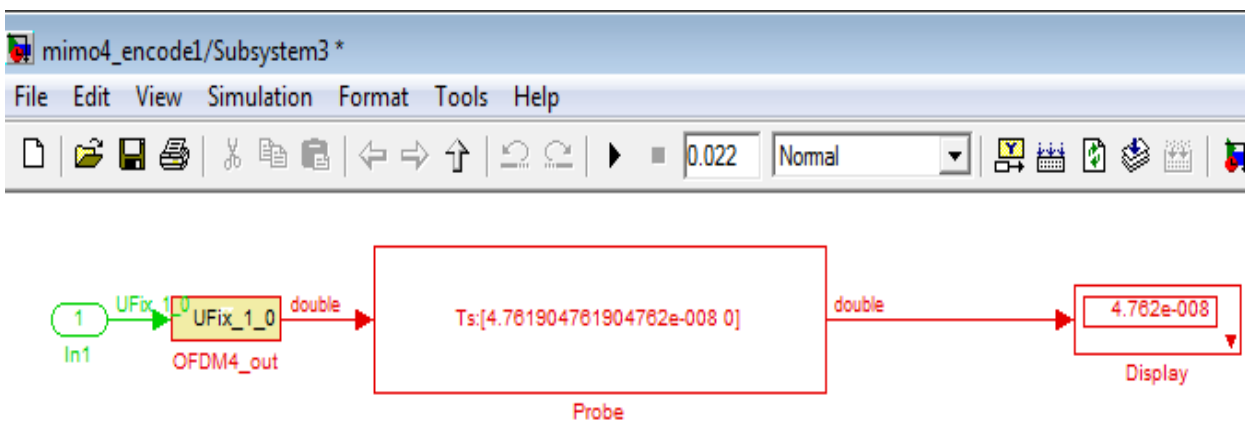

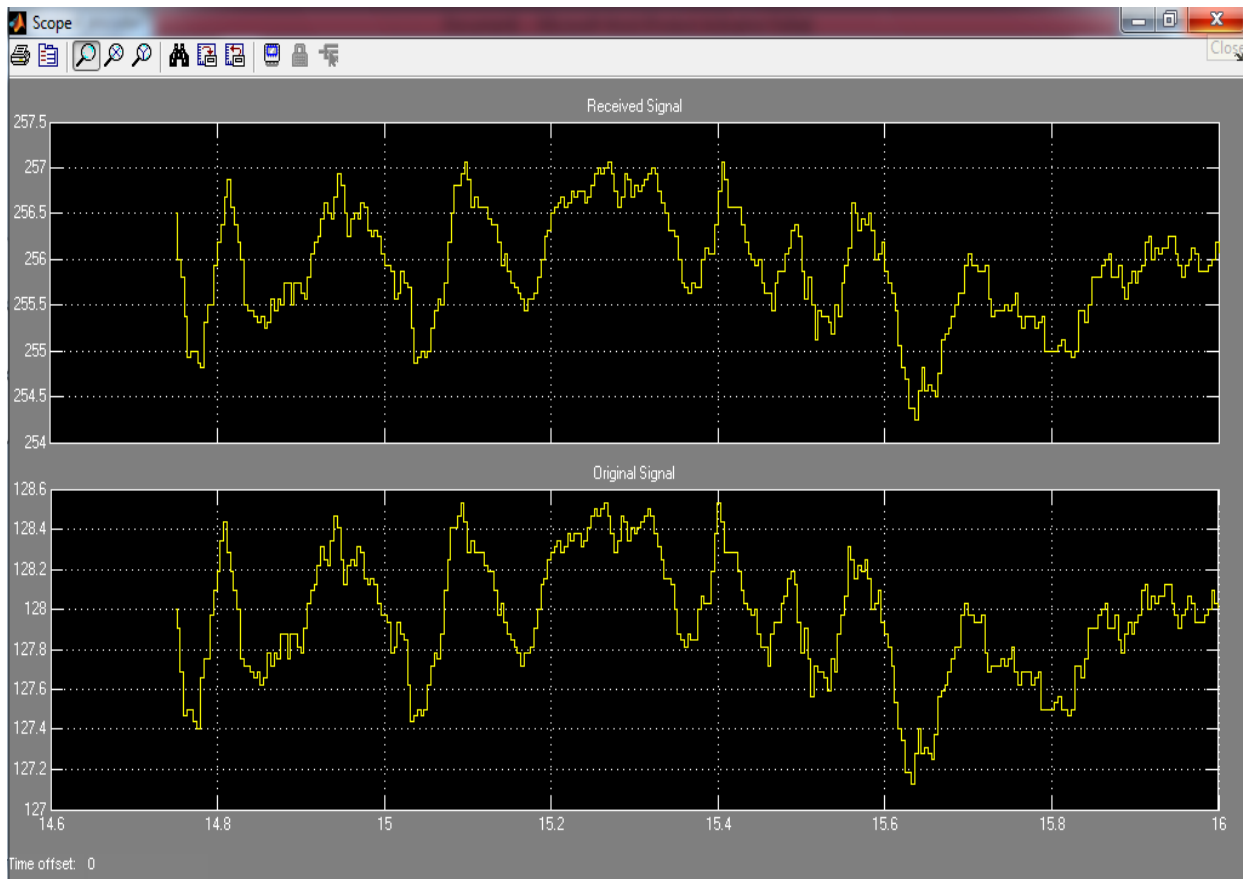**Fig. 4.5. Changed Ts value in probe of Sample Time Block**

Fig. 4.6. MIMO output and input signal

5. CONCLUSION

This paper reviews the MIMO-OFDM, MIMO techniques like space time block code and spatial multiplexing. For a real time audio input a spatially multiplexed 4 x 4 MIMO OFDM transceiver using QAM is designed and implemented on Matlab Simulink. Thus MIMO transmits four data streams through a single channel, thereby can deliver four or more times the data rate per channel without additional bandwidth or transmit power.

6. ACKNOWLEDGMENTS

Our thanks to the experts who have contributed towards development of the MIMO OFDM

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