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Performance Analysis and Hardware Implementation of a 802.lln 4X4 MIMO OFDM Transceiver Using 16-QAM

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***ABSTRACT*— The increasing demand on real time application to achieve high throughput, reliable wireless system and network capacity for fourth generation wireless local area networks is to combine MIMO wireless technology with OFDM. Orthogonal Frequency Division Multiplexing (OFDM), which offers reliable high bit rate wireless system with reasonable low complexity. OFDM does provide large data rates with sufficient robustness to radio channel impairments. OFDM is a combination of modulation and multiplexing and are able to maximize spectral efficiency without causing adjacent channel interference.**

The objective of this paper is to design and implement a base band OFDM transmitter and receiver on FPGA hardware. The transmitter will include blocks like convolution encoder, mapper, parser, IFFT, interleaver and blocks inserting pilot carrier and guard interval at the transmitter side. At the receiver side blocks perform the reverse process are present such as decoder, detection of received symbols, deparsing, FFT, deinterleaving and blocks removing pilot and guard interval.

By implementing a MIMO OFDM baseband transceiver on an FPGA with proper selection of one of the sixteen constellations which vary in terms of the convolution coding rate, the parsing method and modulation type (e.g. data rate 48Mbps using 16-QAM at the code rate of ½ using Spatial Multiplexing) thereby the project is expected to fulfill the need for high-speed data transmission for a wireless communication system with cost effective hardware implementation, also we study the effects of signal to noise ratio(SNR) over Bit error rate(BER), through intensive MATLAB simulation.

Index Terms -Multiple Input Multiple Output, Orthogonal Frequency Division Multiplexing, Spatial Multiplexing, Space Time Block Code, Field Programmable Gate Array, Matlab Simulink, System Generator and Xilinx.

I. INTRODUCTION

The most important character of the standard is MIMO-OFDM, which not only improves the throughput but also the spectrum efficiency and channel capacity[1] One of the techniques being Orthogonal Frequency Division Multiplexing (OFDM), which offers reliable high bit rate wireless system with reasonable low complexity. The new 802.11n standard is predicted to be capable of supporting data rates up to 600 Mbps [1] by deploying the latest communication method such as "MIMO" (Multiple Input Multiple Output). The MIMO operations are based on STBC (Space Time Block Code) and SM (Spatial Multiplexing). The STBC method helps in enhancing Quality of Service (QoS) of the system whereas SM method leads to result in higher capacity in the system[16]. There are several methods to implement the OFDM system like ASIC, microprocessors and microcontrollers and FPGA. The implementation on FPGA is better than on a general purpose MPU in terms of speed and on ASIC in terms of cost.

The goal of this article is to provide a high-level review of the basics of MIMO-OFDM wireless systems with a focus on 4X4 MIMO-OFDM transceiver. The remainder of this article is organized as follows. Following this introduction, part II provides the detail of IEEE802.11n standard. Part III will provide information about MIMO-OFDM System. Part IV Hardware Co-simulation and Graphs Plotted for MIMO OFDM Transceiver System. part V provides the concluding remarks. Finally part VI highlights track for future work.

II. IEEE802.11N STANDARD

IEEE 802.11n standard utilizes MIMO-OFDM as modulation technique. MIMO OFDM system comprises of transmitter and receiver sections. An 802.11 n system has various different parts. Figure 2 illustrates these parts.

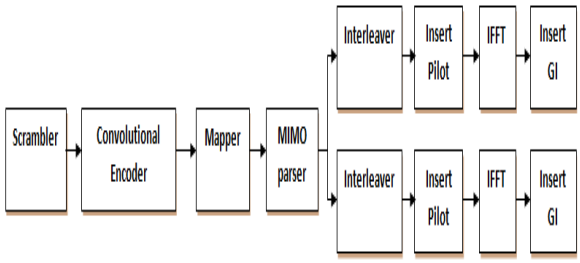

Fig.2.1. 802.11n System Transmitter block diagram.

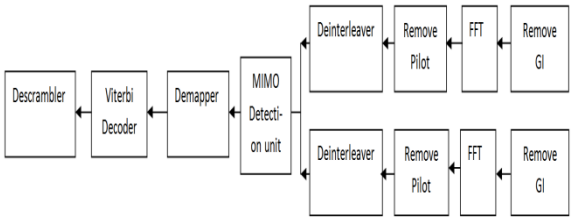

Fig.2.2. 802.11n System Receiver block diagram.

A. *Transmitter side*

Scrambler:

The scrambler transposes or inverts signals at the transmitter to make the message unintelligible at a receiver not equipped with an appropriately set of descrambling device. Scrambling is accomplished by the addition of components to the original signal or the changing of some important component of the original signal in order to make extraction of the original signal difficult.

Convolutional Encoder:

The data bits are encoded using a convolutional encoder. Convolutional encoding with Viterbi decoding is a FEC technique that is particularly suited to a channel in which the transmitted signal is corrupted mainly by Additive White Gaussian Noise (AWGN).

Mapper:

According to the modes of operation the data bits are punctured and mapped with one of the constellations mentioned such as BPSK/QPSK/QAM [1][4]. Puncturing is the process of removing some of the parity bits. This has the same effect as encoding with an error-correction code with a higher rate, or less redundancy. Thus puncturing considerably increases the flexibility of the system without significantly increasing its complexity. Puncturing increases the data rate defined as incase for rate 2/3 which indicates transmitting 3 bits and taking 2 at the output. The data thereby is sent to Multiple- Input Multiple-Output (MIMO) parser.

MIMO Parser:

The MIMO parser performs different operations on input data bits. This operation is based on Space Time Coding (STC) or Spatial Multiplexing (SM). Among the most important STC's are the Alamouti and trellis codes. The D-BLAST and V-BLAST methods are among the most important methods in Spatial Multiplexing [2]. These methods have different complexities and give different error correcting or capacity gains. A parser segments a long bit stream into multiple spatial data streams. The multiple spatial data streams are applied to multiple interleavers.

Interleaver

The interleaver thereby interleaves the bits which correspond to spatial data stream by performing multiple column rotation to increase diversity of the wireless system. There are different types of interleavers such as row-column, helical, odd-even and pseudo-random interleavers.

Insert Pilot:

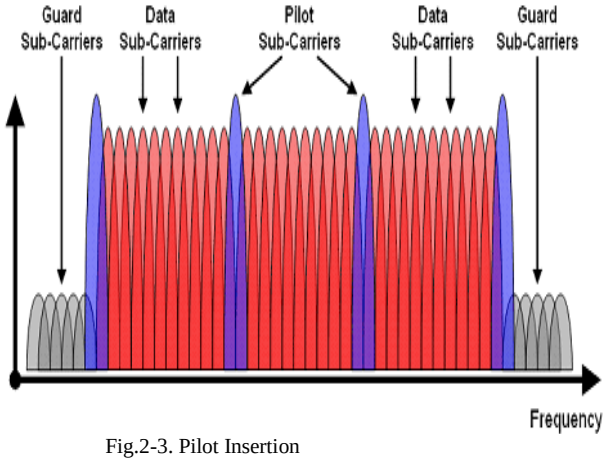

Fig.2-3. Pilot Insertion

By Insert Pilot it is possible to prevent Inter carrier interface (ICI). The pilot inserted to the corresponding sub carriers is used for channel estimation.

IFFT:

The IFFT block transforms frequency signal into time domain. Calculation of FFT/IFFT size:

$$X(k) = \sum_{j=1}^{N} x(j)\omega_N{}^{(j-1)(k-1)}$$

$$X(j) = (1/N)\sum_{k=1}^{N} x(k)\omega_N{}^{-(j-1)(k-1)}$$

The data transmit rates depends on bandwidth and DFT size as shown in the Figure2-3. In a 20-MHz bandwidth, a transmit rate of around 60 Mbps is achieved which is roughly the maximum data rate of the IEEE802.11a standard. 54 Mbps in 64-QAM. [15].

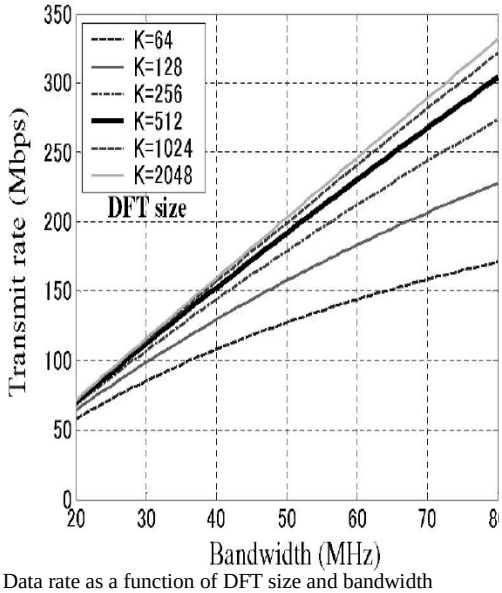

Fig 2-4 Data rate as a function of DFT size and bandwidth

The 64-point DFT is not sufficient to increase the data rate for a bandwidth of 80MHz. By using 512-point DFT a data rate of 300 Mbps can be achieved. The selection of DFT size for various bandwidths is shown in the table 2-1.

Table 2-1 DFT size and Bandwidth

DFT Size	Bandwidth(MHz)	Approximate Data rate(Mbps)
64	20	60
128	40	130
256	60	210
512	80	300

Insert Guard Interval:

The spectra of an OFDM signal is not strictly band limited, linear distortion such as multipath cause each sub-channel to spread energy into the adjacent channels and consequently cause Inter Symbol Interference (ISI). The guard interval is inserted in order to avoid Inter Symbol Interference. A system without a guard interval has a significantly lower bit error rate and requires less bandwidth [2].

Multiple-Input-Multiple-Output (MIMO) antenna systems provide higher data rates up to 100Mbps. The combination of OFDM with MIMO results in less BER and improved Eb/No.

Table 2-2: OFDM Specifications

Given parameters in the specification:	Description
N=64	FFT size or total number of subcarriers (used + unused) are 64
Nsd = 48	Number of data subcarriers are 48
Nsp = 4	Number of pilot subcarriers are 4
Derived Parameters	
Ofdm BW = 20 * 106	OFDM bandwidth
ΔF = ofdm BW/N	Bandwidth for each subcarrier - include all used and unused subcarriers
Tfft = 1/ΔF	IFFT or FFT period = 3.2μs
Tgi = Tfft/4	Guard interval duration - duration of cyclic prefix - 1/4th portion of OFDM symbols
Tsignal = Tgi+Tfft	Total duration of OFDM symbol = Guard time + FFT period
Ncp = N*Tgi/Tfft	Number of symbols allocated to cyclic prefix
Nst = Nsd + Nsp	Number of total used subcarriers
nBitsPerSym = Nst	For QAM the number of Bits per Symbol is fouras number of subcarriers

B. Receiver side

The operations of receiver blocks are opposite to that of transmitter to receive the actual signal.[4] At the receiver, the signal should first be detected. The guard interval is then omitted and the signal is sent to the FFT block. After calculating FFT, the signals are de-interleaved and sent to the MIMO detection unit. This block detects the signals using the channel estimation. The block's operation depends on the method used to code the signals in the transmitter. After signal detection, the received signals are demapped into corresponding numbers. The detected signals are then decoded using a decoder and finally descrambled. At this point the data are ready for sending to the higher level.

Table 2-3 Different data rates with Configuration

Data Rate in Mbps	Constellation	Code Rate	MIMO usage
6	BPSK	½	SFC
9	BPSK	¾	SFC
12	QPSK	½	SFC
18	QPSK	¾	SFC
24	16-QAM	½	SFC
36	16-QAM	¾	SFC
48	64-QAM	2/3	SFC
54	64-QAM	5/6	SFC
12	BPSK	½	SM
18	BPSK	¾	SM
24	QPSK	½	SM
36	QPSK	¾	SM
48	**16-QAM**	**½**	**SM**
72	16-QAM	¾	SM
96	64-QAM	2/3	SM
108	64-QAM	5/6	SM

The design of transceiver with OFDM parameters [2] is as mentioned in the table 2-3. When the transmitter receives data from the higher level, it can transmit data in sixteen different configurations. There are three issues which vary in different configurations [2]. The first one is the constellation used, the second one is the convolutional code rate and third one is the MIMO parsing method. The table below shows these different data rates

III. MIMO-OFDM SYSTEM

Multiple-input multiple-output (MIMO) wireless technology in combination with orthogonal frequency division multiplexing (MIMO-OFDM) is an attractive air-interface solution for next-generation wireless local area networks (WLANs), wireless metropolitan area networks (WMANs), and fourth-generation mobile cellular wireless systems.

3.1 Orthogonal Frequency Division Multiplexing:

Orthogonal Frequency Division Multiplexing (OFDM) is a combination of modulation and multiplexing. In this technique, the given bandwidth is shared among individual modulated data sources. Normal modulation techniques like AM, PM, FM, BPSK, QPSK, etc... are single carrier modulation techniques, in which the incoming information is modulated over a single carrier [1].

OFDM is a multicarrier modulation technique, which employs several carriers, within the allocated bandwidth, to convey the information from source to destination. Each carrier may employ one of the several available digital modulation techniques like BPSK, QPSK, and QAM.

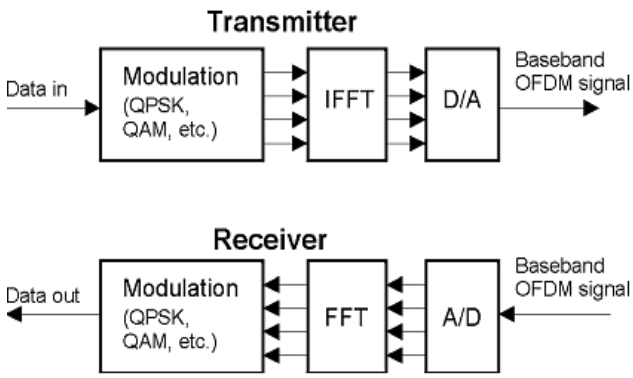

Fig.3.1 OFDM Transmitter and Receiver.

A communications data stream is effectively split into N parallel low bandwidth modulated data streams. Each sub-carrier overlaps, but they are all orthogonal to each other, such that they do not interfere with one another. Each of the sub-carriers has a low symbol rate. But the combination of sub-carriers carrying information in parallel allows for high data rates. The other advantage of a low symbol rate is that inter-symbol interference (ISI) can be reduced dramatically since the symbol time represents a very small proportion of the typical multipath delay [1].

3.2 MIMO-OFDM System:

In MIMO, the system exploits the fact that the received signal from one transmit antenna can be quite different than the received signal from a second antenna. This is most common in indoor or dense metropolitan areas where there are many reflections and multipath between transmitter and receiver [9]. In this case, a different signal can be transmitted from each antenna at the same frequency and still be recovered at the receiver by signal processing.

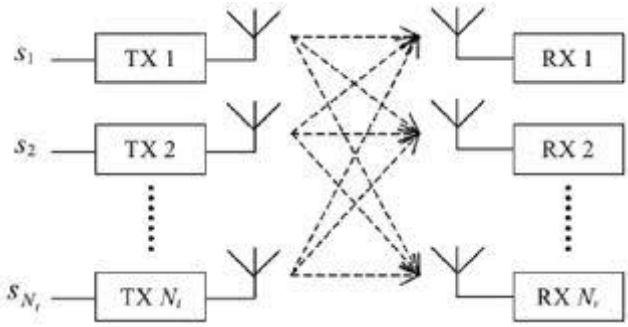

Fig..3.2 Transmit and Receive MIMO channel

3.2.1 Spatial Multiplexing (SM)

In Fig. 3.2, a high-rate bit stream (left) is decomposed into three independent 1/3-rate bit sequences which are then transmitted simultaneously using multiple antennas, thus consuming one third of the nominal spectrum. The signals are launched and naturally mix together in the wireless channel as they use the same frequency spectrum [4][10].

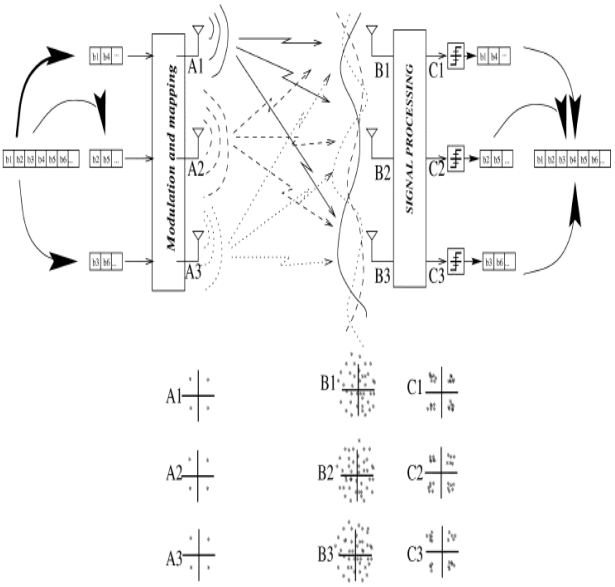

Fig.3.2.1 Basic spatial multiplexing scheme with three Transmitter and three Receiver antennas.

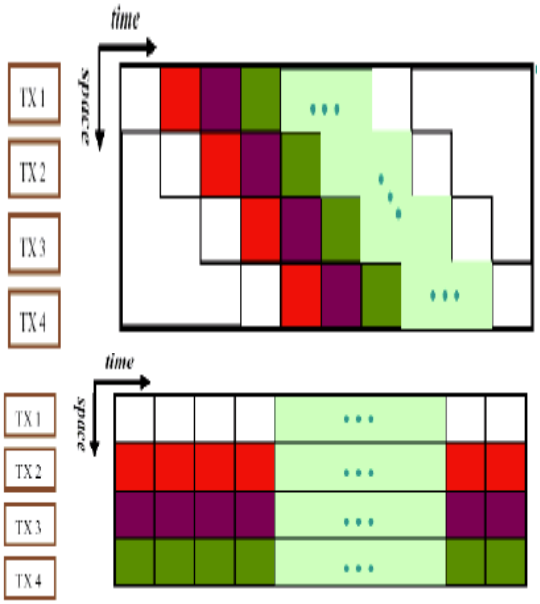

Figure 3.2.2 Transmit coding scheme comparison between (a) D-BLAST and (b) V-BLAST [14]

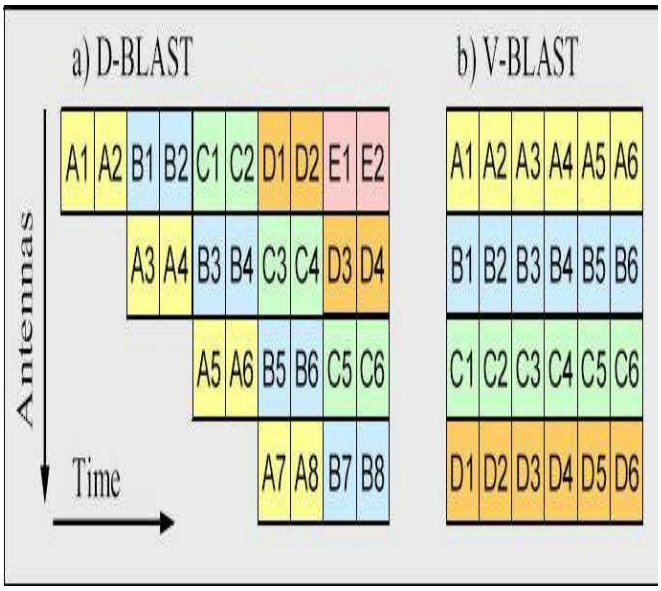

Figure 3.2.3 Layout of code words on the sender side in a) D-BLAST b) V-BLAST with four sending antennas[17].

At the receiver, after having identified the mixing channel matrix through training symbols, the individual bit streams are separated and estimated [9]. This occurs in the same way as three unknowns are resolved from a linear system of three equations. This assumes that each pair of transmit receive antennas yields a single scalar channel coefficient, hence flat fading conditions.

IV. Hardware Co-simulation and Graphs Plotted for MIMO OFDM Transceiver System

This section provides a description on the FPGA and Hardware Co-simulation of MIMO OFDM Transceiver.

A. Introduction to FPGA

A field-programmable gate arrays (FPGA) is a programmable logic device that supports implementations of relatively large logic circuits. FPGA consists of logic blocks for implementing the required functions.

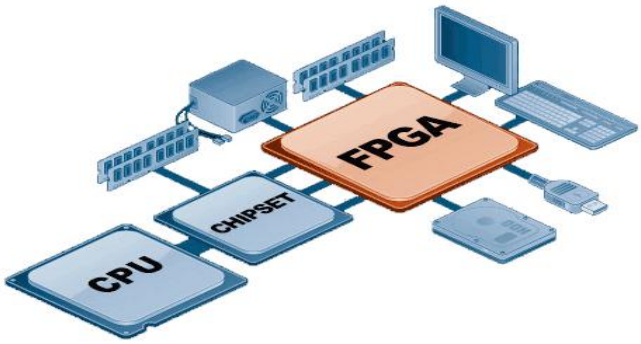

Fig 4.1- Field Programmable Gate Arrays

A FPGA contain three main types of resources: logic blocks, I/O blocks for connecting to the pins of the package, and interconnection wires and switches.

Hence the FPGA has to be programmed every time power is applied. Of this, a small memory chip that holds its data permanently, called a programmable read-only memory (PROM) is included on the circuit board that houses the FPGA. The storage cells in the FPGA are loaded automatically from the PROM when power is applied to the chips.

B. Hardware Co-simulation

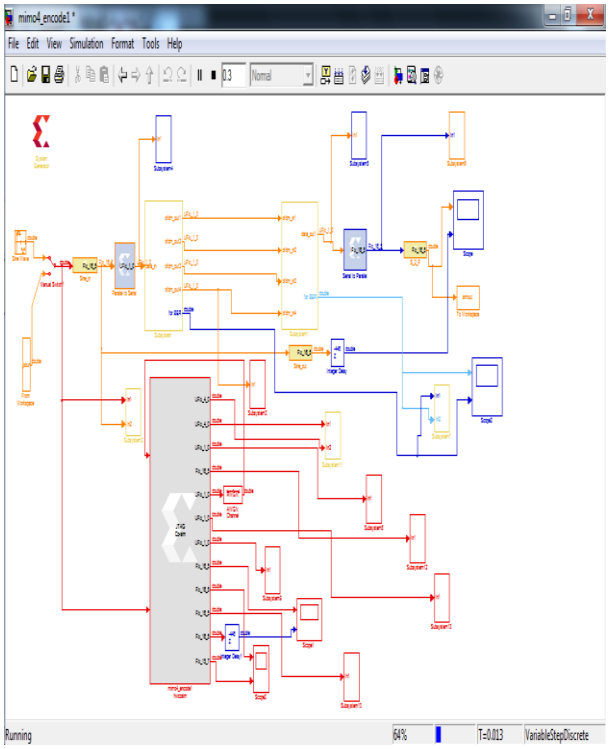

Fig. 4-2 Data Rate Display

The output of the scope can be seen in the Figure 4-3 where the first waveform is the signal which has been achieved at the output of model i.e. received signal and the second waveform is the actual signal which was been fed as input to the model.

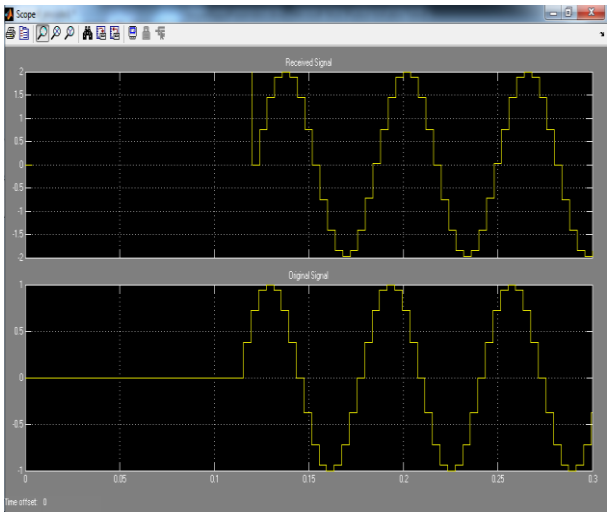

Fig 4-3 Received and Original Signal

C. Graphs Plotted

The BER verses SNR calculations are made from the model and checked with different SNR.

SNR	BER
0	0.00000349
1	0.00000306
2	0.00000284
3	0.00000264
4	0.00000245
5	0.00000222
6	0.00000191
7	0.00000101
8	0.00000101
9	0.00000101
10	0.00000101
11	0.00000101
12	0.00000101
13	0.00000101
14	0.00000101
15	0.00000101
16	0.00000101
17	0.00000101
18	0.00000101
19	0.00000101
20	0.00000101

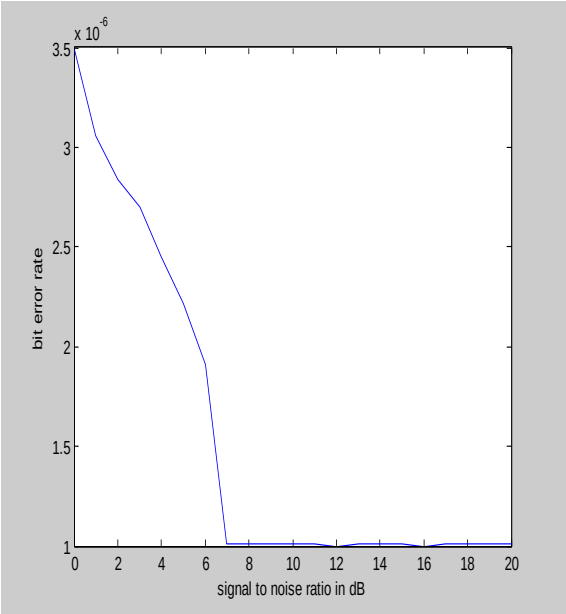

Fig 4-4 . BER v/s SNR for QAM

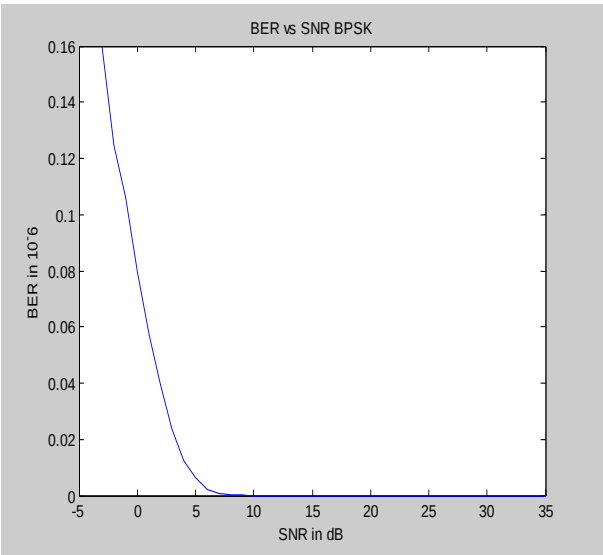

Fig 4-5 BER v/s SNR for BPSK

V. CONCLUSION

MIMO OFDM systems are the answer to our ever increasing data rate needs. By implementing a MIMO OFDM baseband transceiver on an FPGA by proper selection of one of the sixteen configurations the need for high-speed data transmission for a wireless communication system with reasonable prices of hardware implementation is fulfilled.

To conclude, this paper gives the knowledge of implementing a 4 X 4 MIMO OFDM transceiver on hardware with use of Matlab Simulink 2010, Xilinx 12.3, Modelsim 6.5 and DigilentAtlys Spartan 6 FPGA board. The discovered data rate of a 2 X 2 MIMO OFDM model using spatial multiplexing with a convolutional encoder of rate ½ is 48 Mbps whereas from the study of the system, it can be concluded that, by implementing 4 X 4 MIMO OFDM model the data rate achieved is up to 216 Mbps, which further can be increased by changing the input frequency. Xilinx System Generator combined with Matlab Simulink provides an easier and efficient way of developing the FPGA system design and simulating it. Also the hardware co-simulation feature of the software enables easier way to test and debug the design effectively on the actual hardware.

VI. FUTURE WORK

An 8 X 8 spatially multiplexed MIMO OFDM based hardware system can be implemented using FPGA based on similar methodology. Different modulation techniques such as QPSK or QAM accommodating number of subcarriers as 1024 or up to 4096 can be experimentally tried to achieve data rates in multiple of 100 Mbps or more.

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