Simulation and Implementation of MIMO-OFDM System with STBC using GNU Radio and USRP

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Abstract— ***The combination of two technologies Multiple input multiple output (MIMO) and orthogonal frequency division multiplexing (OFDM) can cater very high rate data transmission. MIMO provides increased diversity gain without increasing the transmitting power whereas OFDM provides high data rates as it is a solution for Inter Symbol Interference (ISI) caused in dispersive channels. Here, in this paper the system performance of MIMO OFDM with Space time block coding (STBC) system is simulated using GNU radio software, plotting diagrams of received symbols with and without noise, the FFT and waterfall diagram. Also, OFDM system is implemented on USRP bus series using GNU Radio software and the results are evaluated.***

Index Terms— ***MIMO, OFDM, STBC, GNU Radio, USRP, Alamouti code, Wireless communication***

I. INTRODUCTION

A. Background and Motivation

The rapid increase in demand for high system capacity, high transmission rate and broadband access with high Quality of Service (QoS) has motivated the research of new technologies which can be capable of fulfilling the above requirements. In accordance to Ref. [1], the combination of two technologies: Multiple input multiple output (MIMO) and orthogonal frequency division multiplexing (OFDM) can cater very high rate data transmission. MIMO provides increased diversity gain [2] without increasing the transmitting power whereas OFDM provides high data rates as it is a solution for Inter Symbol Interference (ISI) [3] caused in dispersive channels. Thus, MIMO OFDM is considered to be a one stop solution for various wireless communication systems like IEEE802.11, IEEE802.16, WiFi, WiMax, 3GPP and LTE.

B. Related Work

FER vs SNR performance comparison of OFDM transmitter is carried out between GNU based and industry based implementation in [4]. Whereas, OFDM receiver's PDR measurements are done in [5] to check the performance with different devices with different standards for 10MHz and 20MHz. In [6][7], the authors have transmitted and received packets using OFDM technique implemented on GNU Radio and USRP. Performance of OFDM is evaluated in [8][9][10]

using GNU Radio platform and USRP2 devices. 2X2 MIMO is simulated and implemented using GNU and USRP2 with Alamouti code in [11], beamforming in [12], and spatial multiplexing in [13]. Detailed literature review is elaborated in table 1.

C. Organization

Further organization of the paper is as follows. Section II defines the MIMO-OFDM system model introducing MIMO with STBC and OFDM. Section III is the main project work done on GNU radio and USRP. Section IV and V elaborates the results and conclusion respectively.

II. SYSTEM MODEL

A. MIMO-OFDM

Merger of MIMO with OFDM shows a considerable improvement in channel capacity. As additional complexity is incorporated in channel; ICI cancellation, channel estimation and PAPR reduction becomes fairly complicated. Proposed system Space Time Block Code (STBCs) [20] by Alamouti in US Patent 6185258 February 2001 can be used to reduce the complexity as discussed earlier.

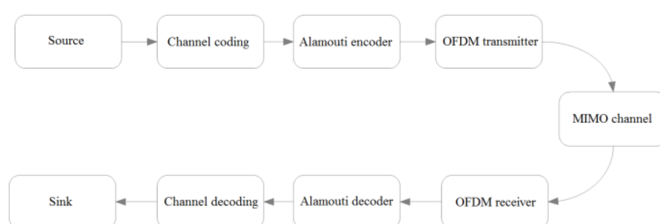

Figure 1. Block diagram of MIMO-OFDM using STBC

At the transmit side, a high speed input data stream is divided into many sub-streams according to the number of subcarriers of the systems. On each subcarrier, input data will be encoded by STBC encoder, then data on each transmit antenna will be processed by IFFT before transmitting. At the receiver side, received signals will be done by an FFT process and applied STBC decoder on each subcarrier. The decoded data will be multiplexed to obtain transmitted data.

Year	Comments
2009	Analyzed QoS in terms of packet received ratio for OFDM system and as FFT length increases the error decreases, increasing the PRR. BPSK performs better than QPSK in terms of PRR. [7]
2010	Implemented IEEE 802.11p frame encoder which generates OFDM frames in digital complex base-band representation. [4]
2011	Has implemented MIMO-OFDM system transceiver for various modulation schemes such as BPSK, QPSK and QAM. Here, to realize MIMO system Alamouti encoder is used for space frequency block coding. [11]
2013	Have presented complete OFDM receiver (IEEE 802.11a/g/p) implemented in GNU radio and USRP N210. [5]
2014	Here, evaluation of practical error performance in Gaussian and racian propagation for three channels estimation/interpolation techniques is implemented. The techniques realized are linear interpolation, second-ordered interpolation and cubic spline interpolation for blind SNR estimation. [10]
2014	Exploitation of MIMO-OFDM system at network level using spatial multiplexing techniques to evaluate the performance and channel condition in terms of SNR vs BER curve and SNR vs. PER curve.[13]
2014	Studied diversity coding for MIMO systems along with adaptive modulation coding is used to help satisfy the increase in demand. The implementation is done for different modulation schemes and different channels are used for BER analysis of MIMO-OFDM system. [14]
2014	Incorporated selection strategy for determination of modulation and coding scheme level dependent upon channel estimation parameter over AWGN and Rayleigh fading channel. [15]
2014	Implemented OFDM transmission and reception of packets using GNU radio and USRP to demonstrate advantages and disadvantages of the system. The authors have also custom build some blocks like cyclic prefix and power allocator. [6]
2015	Analysed and simulated OFDM on GNU radio to studied the effect of frequency and timing offset. As per simulation results increase in offset causes increase in BER leading to packet loss. [16]
2016	MIMO-OFDM system is simulated on GNU and SNR values for the same is calculated for different modulation schemes [17]
2016	The authors have analyzed the performance of enhanced OFDM system on GNU radio and USRP1 [18]
2017	OFDM system is implemented on USRP1 for live video transmission using gsteamer with the help of webcam [19]

Table 1. Literature review of previous work done

B. MIMO with STBC

` Transmission and reception of data using multiple antennas is MIMO system. The data transmitted via channel will undergo NtNr paths from Nt transmit antennas to Nr receive antennas. The received vectors which are received by multiple antennas are decoded into source information by the receiver. A flat fading MIMO system can be modeled as

$$y = Hx + w \qquad (1)$$

Where x and y are transmitted and received signal vectors, respectively, and H and w are the channel matrix and the noise vector, respectively.

Channel capacity of MIMO systems when Channel state information is present,

$$C_{CSI_{perfect}} = E\left[\max_{Q;tr(Q)\leq 1} \log_2 \det(I + \rho HQH^H)\right] \qquad (2)$$

where (:)H denotes Hermitian transpose, _ is the ratio between transmit signal power and noise power, and Q the optimal signal covariance

Channel capacity of MIMO systems when Channel state information is unknown,

$$C_{no-CSI} = E\left[\log_2 \det(I + \frac{\rho}{N_t} HH^H)\right] \qquad (3)$$

To derive full benefits from MIMO systems diversity coding is used. It was first designed for a two-transmit antenna system and is represented as a matrix:

$$C_2 = \begin{bmatrix} c_1 & c_2 \\ -c_2^* & c_1^* \end{bmatrix} \qquad (4)$$

Where * denotes complex conjugate. c1 andc2 are the symbols to be transmitted at two different time instances by two antennas.

It takes two time-slots to transmit two symbols. In the first time slot, two symbols x1 and x2 (in parlance to OFDM) are transmitted simultaneously from two transmit antennas. During the second time slot, x2 is transmitted from first transmitter antenna and x1 is transmitted from second transmit antenna. The Alamouti encoder system for two transmit and two receive system is shown in Figure 2.

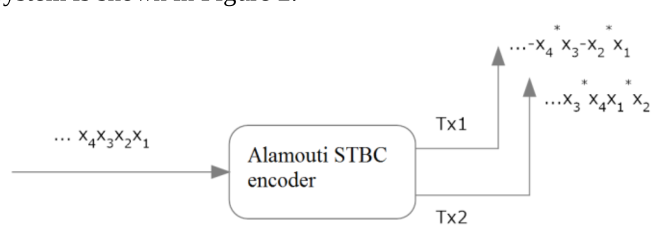

Figure 2. Alamouti encoder for 2x2 system

Using the optimal decoding scheme discussed below, the bit-error rate (BER) of this STBC is equivalent to 2Nr branch maximal ratio combining (MRC). This is a result of the perfect orthogonality between the symbols after receive processing — there are two copies of each symbol transmitted and Nr copies received. Where Nr is the number of receiver antennas. This is a very special to STBC. It is the only orthogonal STBC that achieves rate 1 [21]. That is to say that it is the only STBC that can achieve its full diversity gain without needing to sacrifice its data rate. Strictly, this is only true for complex modulation symbols. Since almost all constellation diagrams rely on complex numbers. However, this property usually gives Alamouti's code a significant advantage over the higher-order STBCs even though they achieve a better error-rate performance.

C. OFDM

Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier communication system. OFDM extends the concept of single sub-carrier modulation by using parallel multiple sub-carriers within a channel. It uses a large number of closely separated orthogonal sub-carriers that are transmitted in parallel. Each of the sub-carrier is modulated with any conventional digital modulation scheme (such as QPSK, 16QAM, etc.) at low symbol rate
.

The OFDM scheme differs from the traditional FDM in following ways[1]:

- Multiple carriers carry single information stream
- Sub-carriers are orthogonal to each other
- A guard interval is added between adjacent symbols to minimize the channel delay spread and inter symbol interference (ISI).

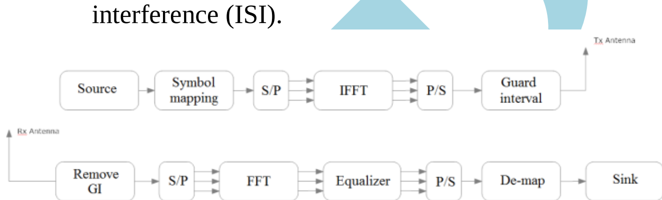

Figure 3. Block diagram of OFDM system

In the frequency domain, sub-carriers are independently modulated with complex data. Inverse FFT operation is performed on the frequency domain sub-carriers to produce the OFDM symbol in the time-domain. After IFFT operation, guard intervals are inserted to each symbol to prevent ISI at the receiver. Without ambiguity, it can be noted that ISI is caused by multi-path delay spread in the radio channel. At the receiver FFT operation is carried out on the OFDM symbols to recover the original transmit data bits.

If N sub-carriers are used, and each sub-carrier is modulated using M-ary signalling, the OFDM symbol alphabet consists of one out of MN number of combined symbols. The low-pass equivalent OFDM signal can be represented as:

$$x(t) = \sum_{k=0}^{N-1} X_k \, e^{j2\pi kt/T_s} \tag{5}$$

Where X_k are the data symbols, N is the number of sub-carriers, and Ts is the OFDM symbol time. The sub-carrier spacing of 1 Ts makes the symbols orthogonal over each symbol period; this property can be expressed as:

$$\frac{1}{T_s}\int_0^{T_s}\left(e^{j2\pi k_1 t/T_s}\right) * \left(e^{j2\pi k_2 t/T_s}\right)dt = \frac{1}{T_s}\int_0^{T_s}\left(e^{j2\pi (k_1-k_2) t/T_s}\right)dt = \delta_{k_1 k_2} \tag{6}$$

where $(\ .)^*$ denotes the complex conjugate operator.

To avoid inter symbol interference in multipath fading channels, a guard interval of length T_g is inserted prior to the OFDM block. During this interval, a cyclic prefix is transmitted such that the signal in the interval $-T_g \leq t < 0$ equals the signal in the interval $(T_s-T_g) \leq t < T_s$. The OFDM signal with cyclic prefix can be presented as

$$x(t) = \sum_{k=0}^{N-1} X_k \, e^{j2\pi kt/T_s}, \ -T_g \leq t < T_s \tag{7}$$

The above low-pass signal can be either real or complex-valued. Real-valued low-pass equivalent signals are typically transmitted at baseband wireline applications such as DSL. For wireless applications, the low-pass signal is typically complex-valued; in which case, the transmitted signal is up-converted to a carrier frequency f_c. In general, the transmitted signal can be represented as:

$$s(t) = R\{x(t)e^{j2\pi f_c t}\} = \sum_{k=0}^{N-1}|X_k|\cos(2\pi[f_c + k/T_s]t + \arg[X_k]) \tag{8}$$

s(t) time domain signal to be transmitted. Sub-carrier separation by k/T_s ensures the orthogonality among sub-carriers.

III. Experimental Setup

A. Simulation on GNU Radio

The GNU Radio is an open source software toolkit for SDR [22]. This toolkit provides a number of radio components, rewritten in Python or C++ programming languages, which can communicate to each other using various data types. GNU Radio offers a graphical design environment, known as GNU Radio Companion (GRC). Python is an object-oriented scripting language that runs on Linux/windows and it has great support for interfacing with C++ code. SWIG (Simplified Wrapper and Interface Generator) is an interface compiler that connects programs written in C++ with Python. GNU Radio can work as a simulation environment but it can also be used to create a real radio system using SDR platforms.

A simulation of MIMO-OFDM STBC systems using GNU Radio is shown in Fig.4.

i. Transmitter

The transmitter side contains data generation, channel coding and OFDM modulation with STBC encoder.

1) Data generation

- Float to Char (in-built): Convert input stream of floats to a stream of char

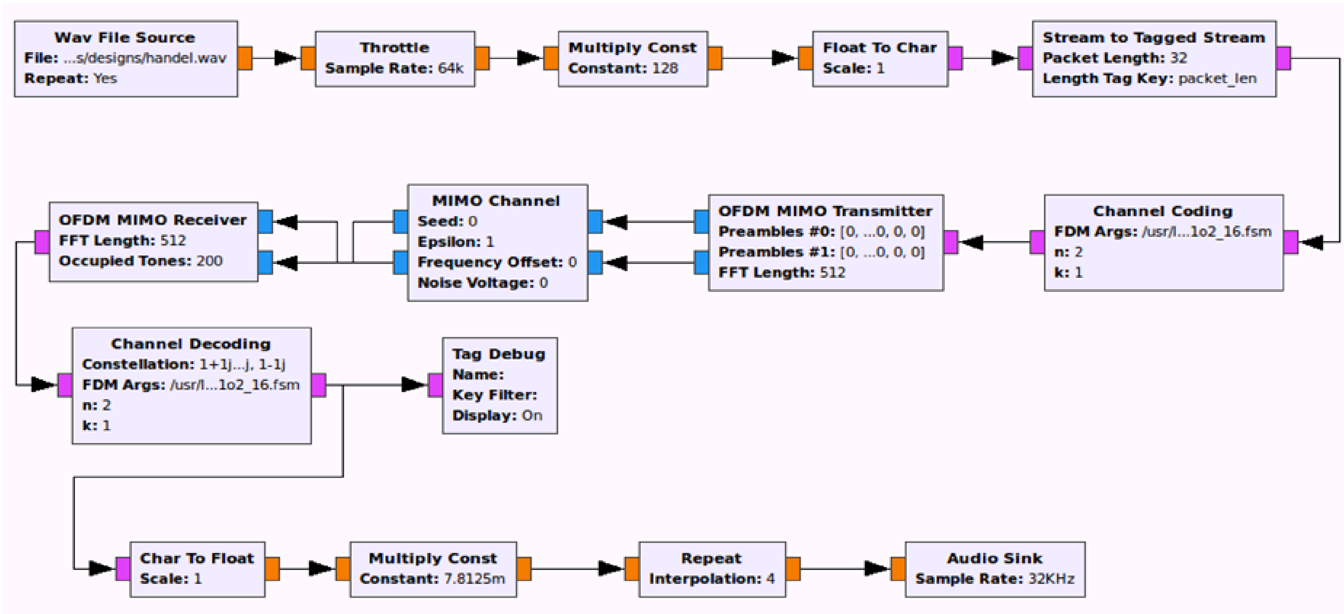

Figure 4. MIMO-OFDM system using GNU Radio

- Stream to tagged stream (in-built): A tagged stream block is a block that works on streamed but packetized input data. Tagged stream blocks use tags to identify PDU boundaries.

2) *Channel coding (fig. 5)*

- Stream CRC32 (in-built): Input: stream of bytes, which form a packet. The first byte of the packet has a tag with key "length" and the value being the number of bytes in the packet. Output: The same bytes as incoming, but trailing a CRC32 of the packet. The tag is re-set to the new length.
- Re-pack bits (in-built): Repack k bits from the input stream onto l bits of the output stream
- Trellis encoder (in-built): trellis conventional encoder is used

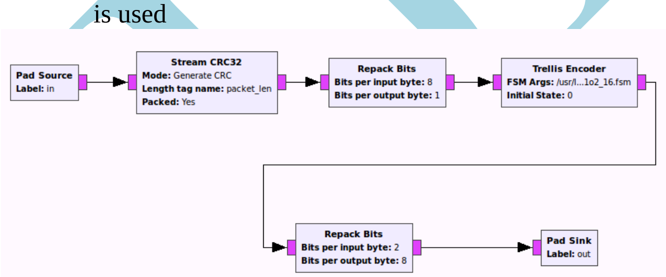

Figure 5. Channel encoding using GNU Radio

3) *OFDM MIMO transmitter (fig. 6)*

- OFDM mapper (modified): it takes a string of bits belonging to a packet and maps to a vector of complex constellation points suitable for IFFT input, divided in proper number of OFDM symbols.
- Alamouti OFDM encoder (new)[23]: STBC coding using Alamouti code is done for compatibility with MIMO channels using channel response.
- OFDM insert preamble (in-built): it inserts a number of OFDM symbols of predetermined constellation points at the beginning of each packet and tags the first one as the first piece of the packet
- FFT (in-built): it computes reverse FFT
- OFDM cyclic prefix (in-built): it adds a cyclic prefix before each piece of packet.

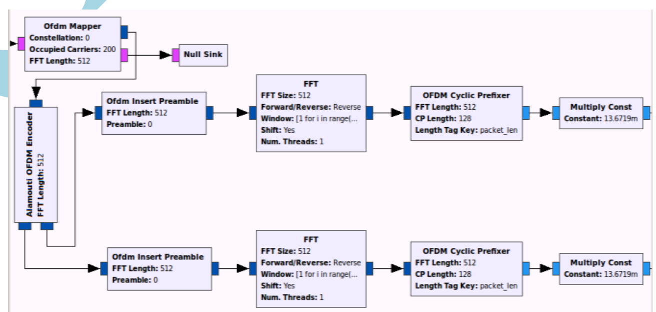

Figure 6. OFDM transmitter with STBC encoder using GNU Radio

ii. *MIMO channel (fig. 7)*

2X2 MIMO scheme is implemented here using channel model block in GNU Radio software.

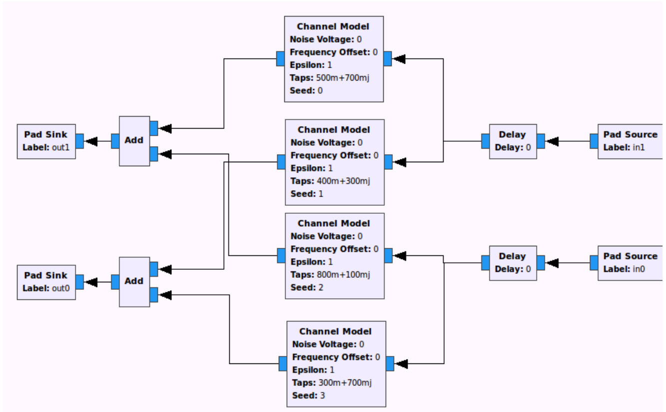

Figure 7. MIMO channels

iii. *Receiver*

The receiver side contains OFDM demodulation with STBC decoder along with digital demodulation and channel decoding.

4) *OFDM MIMO receiver (fig. 8)*

- OFDM demapper (modified): FFT is performed at the receiver's end
- Alamouti OFDM dencoder (new): STBC decoding is done in this block.

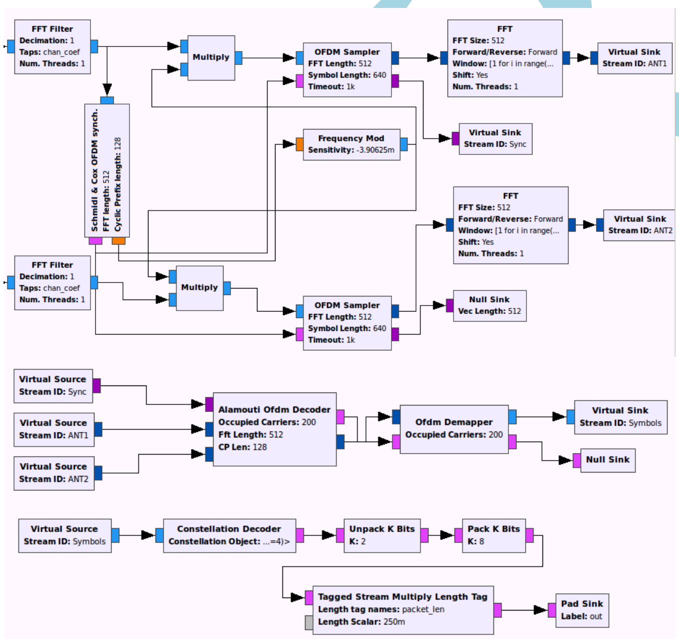

Figure 8. OFDM receiver with STBC decoder using GNU Radio

5) *Channel decoding (fig. 9)*

- Chunks to symbols (in-built): convert chunks of data into symbols as a input to viterbi decoder
- Viterbi combo (in-built): viterbi decoder is used as a decoder for trellis coding

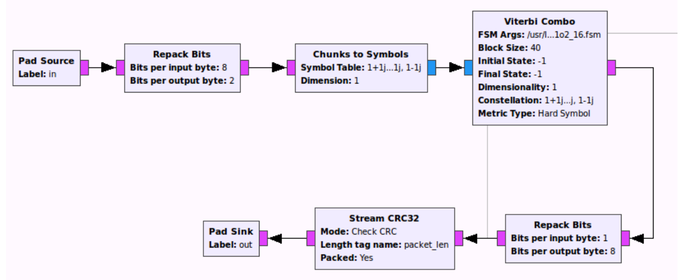

Figure 9. Channel decoding using GNU Radio

B. *Implementation using USRP*

In this paper two USRP 1 devices, two laptops and log periodic antennas. The USRPs used are bus series USRPs from Ettus Research, model name B200 and B210 as an interface between laptop and antennas. Each laptop is using Live USB environment to work on GNU Radio simulation platform. Log periodic antennas are used for real time transmission of MIMO-OFDM system. The complete system setup is shown in figure 10.

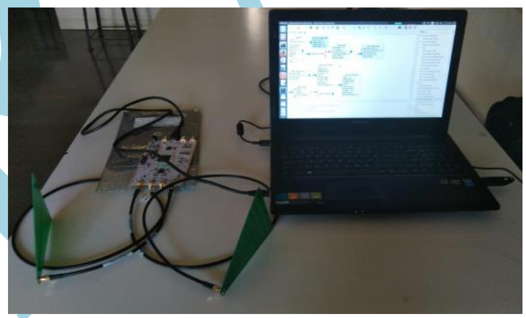

Figure 10. Transmitter implemented using USRP

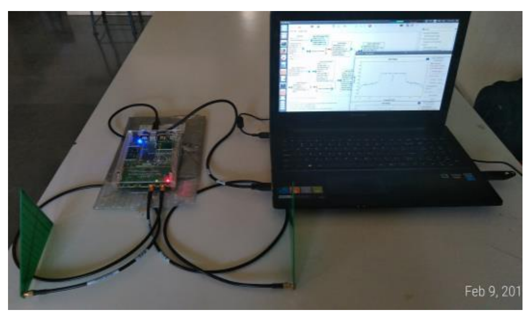

Figure 10. Receiver implemented using USRP

IV. RESULTS

The required parameters for simulation/implementation purpose and their values are listed in table 2. Here, the FFT length is kept 512 which give the best output with trial and error approach.

Parameters	Values
FFT length	512
Occupied tones	200
CP length	128
N_t	2
N_r	2

Table 2. Simulation parameters

The received signal is shown along with its FFT plot, waterfall and constellation diagram (fig. 11, 12, 13, 14 respectively).

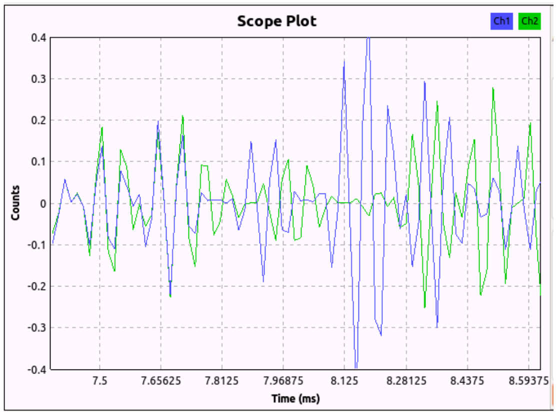

Figure 11. Received time domain signal without noise

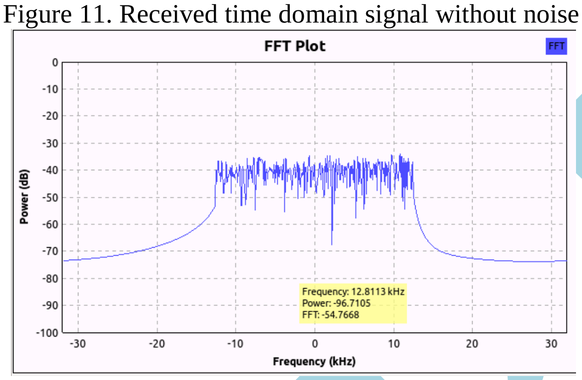

Figure 12. FFT plot of the received signal

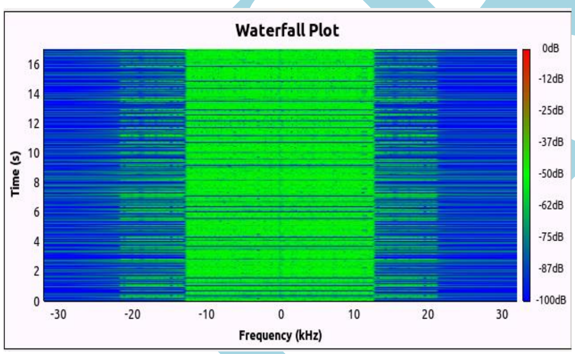

Figure 13. Waterfall for the received signal

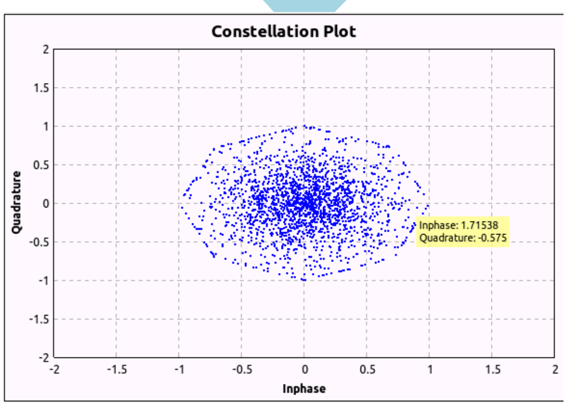

Figure 14. Constellation plot for the received signal

V. Conclusion and Future Work

2X2 MIMO OFDM system using STBC is successfully simulated on GNU Radio platform for file and audio reception. An OFDM system is implemented on USRP bus series using GNU radio software for real-time end to end communication. In conclusion, the radio parameters such as modulation, FFT bin and power used should be carefully chosen to achieve optimum performance of communication.

The next step of the research will be implementing MIMO OFDM for different MIMO schemes using GNU Radio and USRP network series which has the flexibility of LO synchronization as MIMO cable is used.

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References

[1] Jean Armstrong, Senior Member. IEEE, "OFDM for Optical Communication". Journal of Lightwave Technology, Vol. 27. No. 3, February 1, 2009

[2] Helmut Bolcskei, Eth Zurich, "MIMO-OFDM Wireless systems: Basics, Perspectives, and Challenges", IEEE Wireless Communications, August 2006

[3] T. H. T. Hwang, C. Y. C. Yang, G. W. G. Wu, S. L. S. Li, and G. Y. Li. "OFDM and Its Wireless Applications: A Survey". IEEE Trans. Veh. Technol., vol. 58, 2009.

[4] P.Fuxjager, A.Constantini, "IEEE 802.11p Transmission using GNU Radio", 6th Karlsruhe Workshop on Software Radios

[5] Bastian Bloessl, Michele Segata. "Full Paper: An IEEE 802.11a/g/p OFDM Receiver for GNU Radio"

[6] Kshitiz Bansal and Vishrant Tripathi. "OFDM Transmission and Reception of packets using GNU-Radio and USRP-Communications Lab Project".

[7] Arief Marwanto, Mohd Adib Sarijari, Norsheila Fisal, Sharifah Kamilah Syed Yusof, Rozeha A.Rashid "Experimental Study of OFDM Implementation Utilizing GNU Radio and USRP - SDR", Proceedings of the 2009 IEEE 9th Malaysia International Conference on Communications 15 -17 December 2009, Kuala Lumpur Malaysia

[8] Nguyen, Duc Toan. "Implementation o OFDM systems using GNU Radio and USRP"

[9] Jusnaini Muslimin, A.L. Asnawi, A.F. Ismail, H.A.Mohd Ramli, A.Z. Jusoh, S.Noorjannah, Nor F.M. Azmin. "Basic Study of OFDM with Multipath Propagation Model in GNU Platform", IEEE Conference on Wireless Sensors, 2015.

[10] Le Chung Tran, Duc Toan Nguyen, Farzad Safaei, and Peter James Vial. "An Experimental Study of OFDM in Software Defined Radio Systems Using GNU Platform and USRP2 Devices", The 2014 International Conference on Advanced Technologies for Communications (ATC'14),2014

[11] Anna Kaszuba, et. Al., "MIMO Implementation with Alamouti coding using USRP2", progress in electromagnetic research symposium proceedings, Marrakesh, Morocco, Mar 20-23, 2011

[12] Selahattin Gokceli, Merve Uslu, " Implementation of pre-FFT Beamforming in MIMO-OFDM"

[13] Fransesca Martelli, et. Al., "MIMO-OFDM spatial multiplexing technique implementation for GNU Radio", ResearchGate, 2014

[14] B. Siva Kumar Reddy and Lakshmi Boppana, "Adaptive Modulation Coding in MIMO-OFDM for WiMAX using GNU Radio",IEEE Region 10 symposium, 2014
[15] B. Siva Kumar Reddy and B. Lakshmi, "BER Analysis with Adaptive Modulation Coding in MIMO-OFDM for WiMAX using GNU Radio", I.J. Wireless and Microwave Technologies, 2014, 4, 20-34
[16] G Yamuna, T. Padmavathi,Varghese Thattil, "Frequency and timing offset Analysis in OFDM using GNU Radio",International Journal of Computer Applications, volume 126-No.15, September 2015
[17] M.Ushamahesh Singh, Sushil Kakkar and Shweta Rani, "BER performance analysis of OFDM-MIMO system using GNU Radio", MATEC Web of Conferences 57, 01022, ICAET, 2016
[18] Jaime Luque Quispe, Jackelyn Tume Ruiz, Luis Meloni," An SDR implementation of an OFDM transmitter and receiver in GNU Radio", 2016
[19] Octarina Nur Samijayani, et al, "Implementation of SDR for video Transmission using GNU Radio and USRP B200", 2017
[20] Siavash M. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications", IEEE JOURNAL ON SELECT AREAS IN COMMUNICATIONS, VOL. 16, NO. 8, OCTOBER 1998
[21] Vahid Tarokh, Nambi Seshadri, and A Robert Calderbank, "Space-time codes for high data rate wireless communication: Performance criterion and code construction", Information Theory, IEEE Transactions on, 44(2):744–765, 1998.
[22] http:// www.gnuradio.org/doc
[23] http://github.com/gnuradio/ - the source repository for GNU Radio