

# DESIGN, IMPLEMENTATION AND OPTIMISATION OF 4x4 MIMO-OFDM TRANSMITTER FOR COMMUNICATION SYSTEMS

M. Chethan Kumar, \*Sanket Dessai

Department of Computer Engineering,  
M.S. Ramaiah School of Advanced Studies, Bangalore-560058

\*Contact Author e-mail: [sanketdessai@msrsas.org](mailto:sanketdessai@msrsas.org)

## Abstract

Multiple Input Multiple Output (MIMO) uses multiple antennas at both the transmitter and receiver side. In recent times the demand for the use of MIMO systems has increased due to its capability of robustness against Multipath fading and increasing the Spatial Multiplexing Gain and Spatial Diversity Gain. Orthogonal Frequency Division Multiplexing (OFDM) is one of the best digital modulation schemes, where signal is divided into number of narrow band channels to obtain spectral efficiency and minimizing the Inter Symbol Interference (ISI). Thus, combining MIMO and OFDM technologies will improve spectral efficiency, link reliability and spectral gain.

In this paper, MIMO and OFDM techniques are combined to improve the transmitter performance. Software reference model for 4x4-MIMO-OFDM Transmitter for wireless communication system is designed and modeled in MATLAB as well as the same is implemented in C language. The evaluation of Bit Error Rate (BER) and Signal to Noise Ratio (SNR) performance of the OFDM technique combined with Alamouti Space Time Block Codes (STBC) based on two modulation schemes namely QPSK and 16 QAM over AWGN channels is carried out. The developed system model is implemented in C and performance comparison & optimization are carried out using Real View Development Suite (RVDS) by considering different ARM cores.

Performance metrics such as Mean Square Error (MSE) and Peak Signal-to-Noise Ratio (PSNR) are computed for 4x4-MIMO-OFDM transmitter system and performance of whole system is analysed for QPSK and 16 QAM modulation techniques. BER for QPSK is  $10^{-2.6}$  and BER for 16 QAM is  $10^{-1.5}$  dB at a fixed SNR of 10 dB. System developed in C is analysed in RVDS. Profiling results shows that ARM cortex family provides better performance in terms of number of cycles estimated to execution of code and code coverage when compared with lower versions of it. The number of estimated cycles in ARM Cortex A9 is reduced by 8.5% when compared to ARM 1136. The work can be further enhanced by using massive MIMO in place of conventional MIMO.

**Keywords:** 4G, Alamouti STBC, MIMO-OFDM, FFT, 16-QAM, QPSK, MATLAB, ARM1136, Cortex A9, RVDS

## Nomenclature

Data	bit, b
Date rate	bits per second, bps
Cycle	Cycle, s
f	Frequency, Hz
Kbits	Kilo bits, Kb= $2^{10}$ =1024b
Mbits	Mega bits, Mb= $2^{20}$ =1,048,576b
IC	Instruction Count
IPS	Instructions per second

MIPS	Million Instructions Per Second
OFDM	Orthogonal Frequency Division Multiplexing
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RVDS	Real View Development Suite
RISC	Reduced Instruction Set Computer
STC	Space Time Codes
STBC	Space Time Block Codes
STTC	Space Time Trellis Code
SNR	Signal to Noise Ratio
ZP	Zero Padding

## Abbreviations

ASK	Amplitude Shift Keying
ARM	Advanced RISC Machine
BER	Bit Error Rate
CC	Code Coverage
CP	Cyclic Prefix
DFT	Discrete Fourier Transform
FSK	Frequency Shift Keying
FEC	Forward Error Correction
FT	Fourier Transform
FFT	Fast Fourier Transform
IC	Instruction Count
IPS	Instructions Per Second
ISI	Inter Symbol Interference
IFFT	Inverse Fast Fourier Transform
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output

## 1. INTRODUCTION

Wireless communication involves the transfer of data without the use of wires. The earliest uses of wireless technology were very limited and data transferred was minimal, hence the available spectrum was sufficient. Communication technology is growing day by day, and system devices are reducing in size as well as being capable of increased processing power. With the growth in wireless communication, customers are demanding more improved and attractive applications, due to which there is a need for improvement in capacity of the available wireless spectrum. Many major technologies have been

developed to meet user requirements. 4G technology will provide high data rate and capacity. This uses Orthogonal Frequency Division Multiplexing technology (OFDM) and multiple input multiple output (MIMO). This will increase the spectral efficiency as well as data rate. MIMO-OFDM system is a combination of MIMO and OFDM technologies. MIMO is an antenna technology which uses multiple antennas at both the receiver and transmitter side. OFDM is the one of the best digital modulation techniques which splits the signal into several narrow band channels to obtain spectral efficiency. Some of the features of 4G technologies are supporting multimedia, video streaming, internet and other broadband services. 4G can achieve better spectral efficiency, thereby providing high speed and high capacity.

MIMO uses multiple antennas at both the transmitter and receiver side. MIMO systems take advantage of the multiple signals to improve the quality and reliability of the transmitted information signal as the information in wireless channels is mainly affected by multipath fading. Multipath results in the multiple copies of the transmitted information at the receiver with some delays. OFDM uses the spectrum very efficiently by overlapping the sub carriers. It increases the data rate, reduces the ISI (Inter Symbol Interference) and utilises the spectrum very effectively which is required for transmission of video and other multimedia messages.

## 2. PROBLEM STATEMENT

The available spectrum is fixed but the demand for high data rate and high reliability is growing day by day to suite the more improved and attractive applications. Many major technologies have been developed to meet user requirements. 4G technology will provide high data rate and capacity. This uses orthogonal frequency division multiplexing technology (OFDM) and multiple input multiple output (MIMO). Aim of this paper is to design, implement and optimize the 4x4 MIMO – OFDM transmitter. The motivation of this paper is to design, implement and optimize a 4x4-MIMO-OFDM transmitter software architecture. The idea behind developing the MIMO-OFDM transmitter is to get the advantage of both MIMO technology and the OFDM technology in achieving higher data rate, spectral efficiency and reliability.

## 3. SYSTEM REQUIREMENTS

The following are the system requirement specifications arrived for different subsystems of the system

- OFDM System generally consists of different sub blocks namely FEC encoder, Interleaving Block, Modulation Block, and IFFT block and STBC block.
- MIMO system typically consists of  $m$  transmit antennas and  $n$  receive antennas.

In this system channel is assumed to be a static channel and is known perfectly at the receiver for all the systems being developed.

## 4. METHODOLOGY

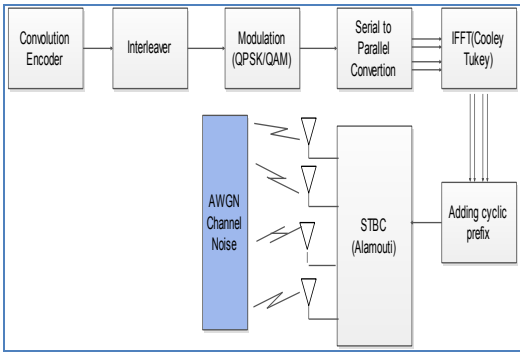
- Review on various techniques/algorithms of the MIMO-OFDM transmitter has been carried out.
- Study and understand the embedded platforms and its architecture and other implementation issues of MIMO-OFDM transmitted based on the reviewed literature.
- Design specifications of the 4x4 MIMO-OFDM transmitter has been arrived based on the reviewed literature and study carried out.
- Design specifications of the implementation issues of the 4x4 MIMO-OFDM transmitter has been arrived based on the reviewed literature and study.
- Design and Modelling of the 4x4 MIMO-OFDM transmitter using different algorithms/techniques has been carried out using the MATLAB tool based on the literature review and the study carried out.
- Performance estimation of the 4x4 MIMO-OFDM transmitter and its different algorithms/techniques has been analyzed based on the modelled design.
- Implementation of the 4x4 MIMO-OFDM transmitters have been carried out using C and Assembly coding for embedded platforms using keil/RVDS/CCS for ARM cores and DSP and its performance estimation has been carried out based on the designed model.
- Optimization techniques have been applied to optimize the implementation of 4x4 MIMO-OFDM transmitters for the embedded platforms based on the design and implementation performance estimations.
- Functionalities test has been carried out on the optimized 4x4 MIMO-OFDM transmitter and transmitter based on the design specifications, implementations specifications.
- Verification of the optimized code has been carried out to meet the design specifications.

## 5. DESIGN AND SOLUTION PROCEDURES

A basic 4X4 MIMO OFDM's transmitter block diagram is shown in Figure 1. Here 4x4 is of the form  $N \times M$  where  $N$  is the number of antennas at the transmitter side and  $M$  represents the number of antennas at the receiver side. The block diagram shows different blocks, namely the FEC coder, used to control the error over the channel.

The Bit Interleaver block is used to logically reorder the data. The Mapper block uses Quadrature Amplitude Modulation (QAM), used which is followed by serial to parallel converter. After converting the signals into parallel data all the data from the different sub carriers are added to get the OFDM signal using the IFFT block. Finally after adding cyclic prefix the signals are up converted to RF and are transmitted through the antennas. Modulated symbols are split into four sequences of  $s_0$ ,  $s_1$ ,  $s_2$  and  $s_3$  symbols. Corresponding index value from each sequence is arranged in the form of 4x4 code matrix or STBC matrix. Code matrix  $X$  is multiplied with channel matrix  $H$  and mixed with AWGN noise to obtain the signal  $Y$  at

the receiver. Alamouti STBC 4x4 implies the principle of Space Time Block Coding with 4 transmits antennas and 4 receive antennas. Modulated symbols are subjected to Alamouti Precoding scheme such that information is sent over four antennas satisfying the principle of orthogonality. The coded data is mixed with AWGN noise. At the receiver, recombining techniques are implemented to estimate the original symbols.



**Fig. 1 Block Diagram of MIMO-OFDM Transmitter System**

### 5.1 Flow Charts for Solution Procedures

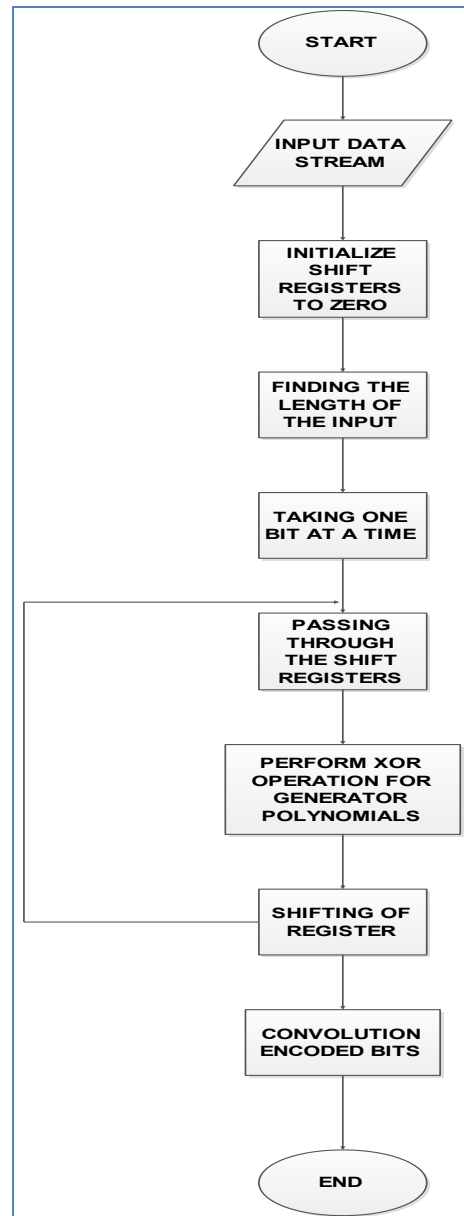
Initially all the shift registers are set to zero, input bits are taken one at a time and passed through the shift register. XOR operations of the bits are performed depending on the generator polynomial considered, for every one bit of data passed 3 encoded bits are added.

After the XOR operation performed depending on the 3 generator polynomials, the output at the each generator polynomial is saved in a variable. Shift register are shifted when each is taken in. Finally all the bits are concatenated which is the output of the convolution encoder. Figure 2 shows the flow chart for the convolution encoder.

Figure 3 shows the flowchart for implementation of alamouti STBC 4x4. 16 QAM modulated symbols are split into four sequences of  $s_0$ ,  $s_1$ ,  $s_2$  and  $s_3$  symbols. Corresponding index value from each sequence is arranged in the form of code matrix or STBC matrix 4x4. Code matrix  $x$  is multiplied with channel matrix  $h$  and mixed with AWGN noise to obtain the signal  $y$  at the receiver. Alamouti STBC 4x4 implies the principle of space time block coding with 4 transmit antennas and 4 receive antennas.

## 6. RESULTS AND DISCUSSIONS

This section deals with the results of the implemented 4x4 MIMO-OFDM Transmitter. Figure 4 shows the BER vs SNR for 4x4-MIMO-OFDM system with the QPSK modulation technique. For 4x4-MIMO-OFDM Transmitter if QPSK modulation is used then number of bit error is 11737 bits for 73728 of transmitted bits. For the 802.11a OFDM standard, as the bandwidth is around 20MHz, the expected minimum sampling frequency is 20MHz. If 128 sub carriers are used then frequency spacing between the two subcarriers is 156.250 kHz. The number of sub carriers is 120 and length of the cyclic prefix is 8 then the data rate of transmitter is 140 Mbps.



**Fig. 2 Flowchart for Convolution Encoder**

Figure 5 shows the BER vs SNR for 4x4-MIMO-OFDM system with the QAM modulation technique. For 4x4-MIMO-OFDM Transmitter if QAM modulation is used then number of bit error is 21078 bits for 73728 of transmitted bits at zero dB. For the 802.11a OFDM standard, as the bandwidth is around 20MHz, the expected minimum sampling frequency is 20MHz. So if 128 sub carriers are used then frequency spacing between the two subcarriers is 156.250 kHz. The number of sub carriers is 120 and length of the cyclic prefix is 8 then the data rate of transmitter is 280 Mbps.

Implemented C code is used in RVDS to run on different ARM cores and performance analysis of the different cores is studied. Profiling in RVDS shows the performance of the codes, like bottle necks in code, code coverage by the processor. Stack utilization of the codes, cycle per instruction and average time taken to execute instructions. By running on the different cores

and analysing it, the best core for the application of the 4x4-MIMO-OFDM Transmitter can be selected.

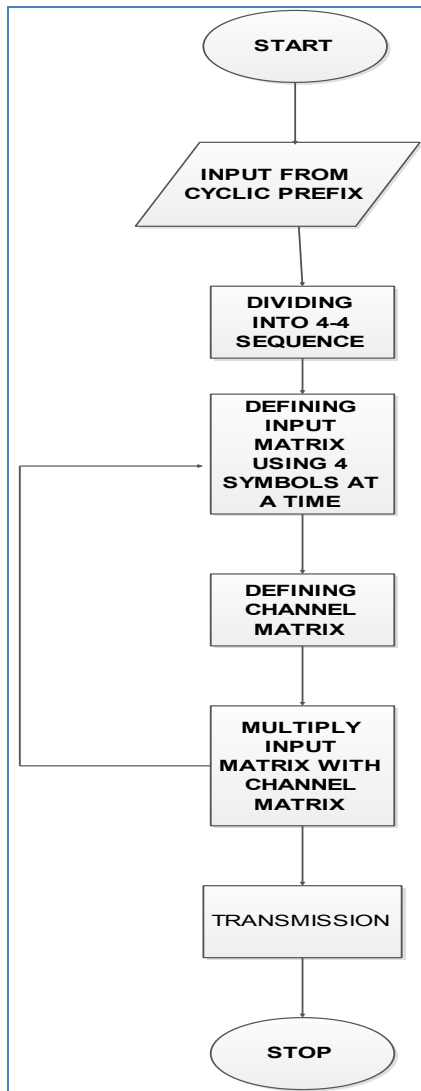


Fig. 3 Flowchart for Alamouti STBC

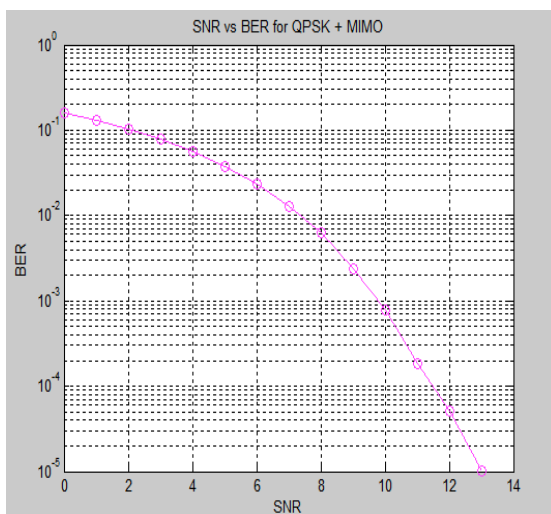


Fig. 4 SNR V/S BER for QPSK

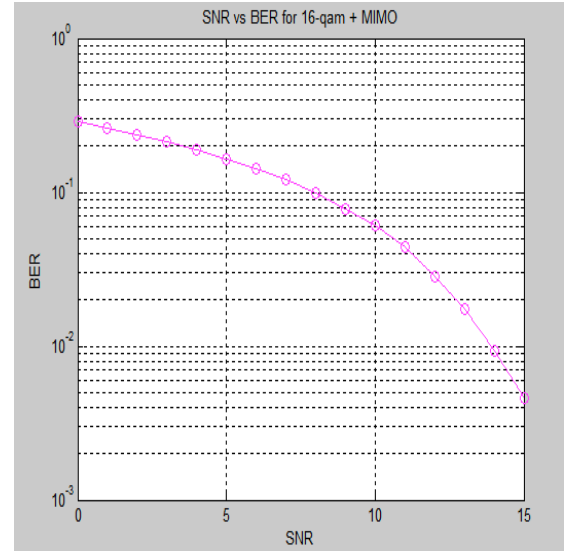


Fig. 5 SNR V/S BER for 16QAM

Table 1 shows the summary of profiling output for different ARM cores. Figure 6 shows the profiling graph for the ARM Cortex A9 core. Left hand side top shows the over analysis section. The overall analysis section gives the information about the, total time, execution count and sampling information, number of estimated cycles (11,244,685) average instructions per second (3,116,216).

Table 1. Profiling of MIMO-OFDM Transmitter with ARM Cores

ARM Core	Number of Instructions	Average Instruction /Second	Number of Cycles Estimated	CC b Instru tion
ARM926	8,653,896	2,060,451	13,693,137	62.18%
ARM1136	8,653,896	14,422,653	12,299,545	61.71%
Cortex A5	7,790,541	2,513,077	11,244,685	62.28%
Cortex A9	7,790,541	3,116,216	11,244,685	62.28%

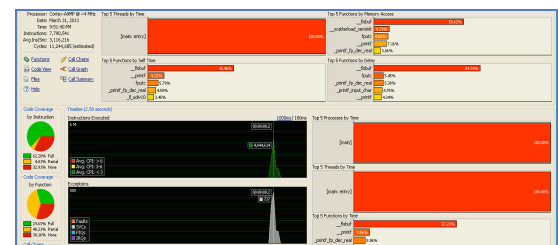


Fig. 6 Profiling Graph for ARM Cortex A9

The code coverage pie charts are located in the bottom left and it gives a look at percentage of instruction and functions executed in the code during the execution in ARM Cortex A9. The code coverage by instruction pie chart shows graphically the percentage of executed assembly instructions in ARM Cortex A9. Figure 7 shows the call summary of the ARM Cortex

A9 before optimization. For cortex A5 MP Time and average time for matrix multiplication function is 0.92% and 5.48% respectively.

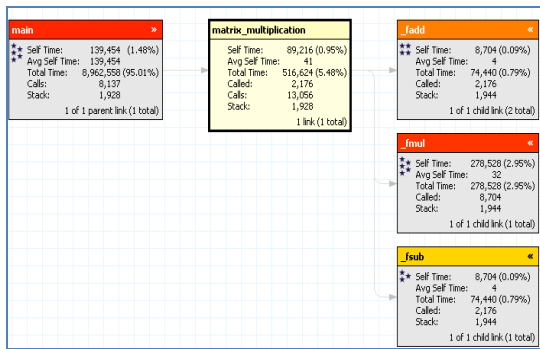


Fig. 7 Call Summary for ARM Cortex A9

### 6.1 Results obtained after Optimisation

Optimisation is process of reducing size of the code by not affecting the final result of it. Optimisation is carried out by using optimising techniques like dead code removal, loop unrolling methods. After optimisation the time taken to execute the code has been reduced. Figure 8 shows the optimised profiling graph for the ARM cortex A9. Number of estimated cycles after optimisation is reduced by 16% and code coverage is increased by 0.58%. Figure 9 shows the call summary of the ARM cortex A9 after optimisation, time taken by the function matrix multiplication is reduced by 0.58% in time.

different modulation techniques like QPSK and 16 QAM. Each sub block of the system developed in MATLAB is tested and validated using inbuilt MATLAB functions. The working of the integrated system is tested and validated using the stubbed receiver. this project are ARM 926, ARM 1176, ARM Cortex A5 MP, and ARM Cortex A9. Finally optimisation of C code is carried out.

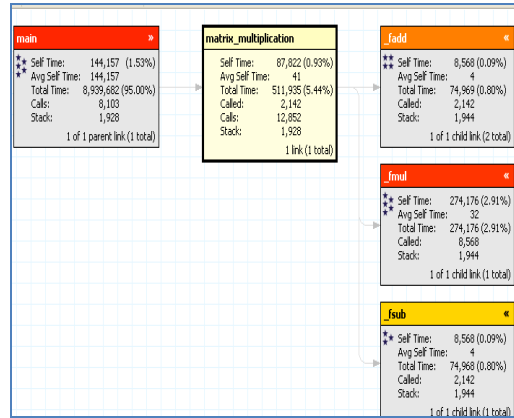


Fig. 9 Call Summary after Optimisation for ARM Cortex A9

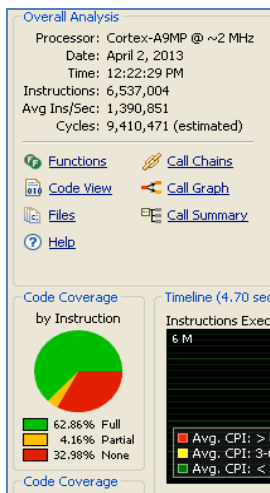


Fig. 8 Optimised Profiling Graph for ARM Cortex A9

## 7. CONCLUSIONS

Software reference model for the 4x4-MIMO-OFDM transmitter is designed using MATLAB and the same algorithm is implemented using C language. Performance metrics such as Signal to Noise Ratio (SNR), Bit Error Rate (BER), Mean Square Error (MSE) and Peak Signal-to-Noise Ratio (PSNR) are computed for 4x4-MIMO-OFDM transmitter. Performance of the system is analysed by using