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Performance Comparison and FPGA Synthesis of MNLMSNCMA Adaptive Beamforming Algorithm

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Abstract – The utility of the Smart antenna has proven to be successful in the domain of wireless communication system design. Beamformer is considered as the potential entity that enables the smart antenna functionality. Performance of the smart antenna largely depends on the nature and characteristics of beamforming algorithm and technique adopted in the design of beamformer. Developments in the field of software tools for simulation and synthesis of algorithms have made possible for their application in the system design process. In this paper a new hybrid adaptive beamforming algorithm known as modified normalized least mean square- normalized constant modulus algorithm (MNLMSNCMA) is presented. Further, the proposed MNLMSNCMA algorithm is synthesised followed by its simulation using Matlab and Mentor Graphics tools. The simulation results in terms of array response gain and resource utilization for Altera's Cyclone V device is presented. It was observed that the proposed MNLMSNCMA algorithm provides increased gain of major beam and reduced gain of side lobes compare to CMLMS algorithm.

Index Terms – Smart Antenna, FPGA Synthesis, Blind Adaptive Beamforming, LMS, CMA,

1. INTRODUCTION

An antenna in its simplest form is a transducer which has the ability to transform electrical signal in to electromagnetic radiations and vice-versa. With the advancements in the wireless communication system design and semiconductor integration technology, an antenna has been reshaped as a "smart antenna". Smart antenna is basically an integration of normal antenna with signal processing algorithm. The usage of signal processing algorithm provides a means of controlling or designing the antenna performance parameters such as antenna gain, bit error rate (BER) and half power beamwidth (HPBW). Advancements in the multimedia communication domain have increased the number of users drastically in the recent pasts and it is expected to grow further. This Users' growth has posed challenge for the researchers for the design of system that ensures optimum utilization of existing resources such as frequency spectrum. At the same time users expectations of improved performance at low cost is another dimension of challenge in design of wireless communication system. Demand for improved performance and applications of smart antenna is enforcing for the research in the design and development of them [1] [2].

Smart antenna design involves the development of beamforming algorithm that causes the antenna radiations to be concentrated in desired directions and nulls in the direction of interferences. In literature beamforming algorithm are broadly categorized as blind algorithms and non-blind algorithms. Blind algorithms are those which do not require any synchronisation or training signal for their functioning such as constant modulus algorithm (CMA). Algorithms that need some kind of reference signal in terms of either temporal or spatial are known as "non-blind algorithms" such as Multiple Signal Classification (MUSIC), Least Mean Square (LMS). Performance of the smart antenna largely depends on the beamformer module which is the hardware implementation of the beamforming algorithm.

Beamforming algorithms performance can be assessed by the rate of convergence and feasibility of its hardware implementation platform such as digital signal processor (DSP) or field programmed gate array (FPGA). Non blind algorithms convergence better but the requirement of reference signal causes redundancy and estimation of direction of arrival (DOA) will increases computational complexity. On the other hand blind algorithms overcome the limitations of non blind ones but, at the cost of poor convergence rate. Hence, combination of non-blind and blind algorithms known as "hybrid algorithms" will be the suitable combination in the smart antenna system design [3][11].

Blind adaptive beamforming algorithms offer benefits of reduced computation burden compare to their non-blind counterparts, but they are poor in convergence. Hybrid adaptive beamforming algorithms are a class of beamforming algorithms which is combination of both blind and non-blind algorithms. Hence, hybrid adaptive beamforming algorithms offer the combined benefits of reduced computation burden and faster convergence.

In this proposed work a new kind of hybrid adaptive beamforming algorithm known as MNLMSNCMA is proposed. MNLMSNCMA algorithm is based on the model as proposed in [4]. The initial weight vector for antenna array elements consideration in the entire stochastic gradient based algorithm is zero and therefore it takes certain amount of iterations for the system to reach convergence. In our proposal we have considered the initial weight vector of the form [5], therefore the system will be convergence ready.

For the hardware implementation of beamforming algorithms FPGA devices are preferred over the DSP due to the ability of reconfigurability and performance [6]. Development of simulation and synthesis tools of algorithms and FPGA architecture the prototyping of any system has been simplified. The proposed algorithm is simulated using MATLAB and FPGA synthesis is performed using Precision plus synthesis tool of Mentor Graphics. Performance of the algorithm in terms of array gain is presented and the hardware resource utilization for Altera Cyclone V family of devices is presented. From the simulation results, it was observed that the proposed algorithm has produced increased array gain with slightest of modification in the structure. The proposed MNLMS-NCMA was synthesised using Precision plus synthesis tool and the resource utilization of the selected FPGA device is also presented.

The rest of the paper is organized as objective and scope of carried out work in section 2, structure of the proposed algorithm is presented in section 3, simulation results are discussed in section 4 followed by the conclusion in section 5.

2. OBJECTIVE AND SCOPE

The design challenges in wireless communication domain are ever increasing due to the users' demands and requirements for improved performance. Developments in the simulation and synthesis tools and rapid growth in semiconductor integration technology has been the motive for the research in this field [2]. To achieve efficient utilization of frequency spectrum and the reduction of interference in wireless communication applications, smart antenna will be very much productive [7]. Smart antennas have been efficiently utilized in all wireless communication devices such as software defined radio (SDR), mobile or cellular communication and multimedia communication. Hence, there is a need for continuous and constant research in the field of smart antenna design in making them better [8] [9].

Beamformer is the main constituent of smart antenna which relies on the beamforming algorithm. The main objective in this work is to develop an adaptive beamforming algorithm for the beamformer. The concept of hybrid beamforming algorithms was developed to overcome the poor convergence of blind beamforming algorithms. Hybrid beamforming algorithms are developed by combining blind algorithms with non-blind algorithms (TR or SR). In this work a new hybrid beamforming algorithm known as modified normalized least mean square- normalized constant modulus algorithm (MNLMSNCMA) is proposed. The proposed MNLMSNCMA algorithm is simulated in Matlab environment and the results in terms of antenna array response and optimum weight vectors are presented.

Beamformer design involves hardware implementation of beamforming algorithm such as DSP, FPGA or ASIC. The capabilities and performance of FPGAs have made them as best alternatives for the beamformer implementation over other processors. The design process of smart antenna for any communication system can be simplified by exploration of simulation and synthesis tools. An approach for faster design of beamformer for smart antenna for NCMA using Mentor Graphics is presented in our previous work [2]. In this work the FPGA RTL synthesis was performed for MNLMS-NCMA algorithm. The scope of this work is limited to RTL synthesis for FPGA implementation of the proposed MNLMS-NCMA algorithm.

3. PROPOSED BEAMFORMING ALGORITHM

Mathematical model of the smart antenna with uniform linear array and concept of array weighting or beamforming can be found in our previous work [1] and [10]. Here we restrict our presentation to the development of MNLMSNCMA. Figure 1 shows the proposed MNLMSNCMA model.

To achieve beamforming, it is very much needed to determine the array response vector or array image of an antenna array. Array response vector of uniform linear antenna array represented by $A(\theta)$ for the desired direction 'θ' is given by [1][4];

$$A(\theta) = [1, e^{j\phi}, e^{j2\phi}, \ldots\ldots.. e^{j(N-1)\phi}] \quad (1)$$

Where ϕ is the phase difference given by, $\phi = \frac{2\pi d \sin\theta}{\lambda}$

'θ' = desired direction of beamforming to be achieved,

'd' = distance between antenna array elements i.e. $\lambda/2$,

'N' = number of array elements,

'λ' = wavelength of the received signal.

In this proposed model, the initial vector for both the NLMS and NCMA is modified as [5] so as to start the system at convergence. Initial vector for the optimal weight calculation is given by the following equation;

$$W_{initial} = \frac{X}{X^T * X} \quad (2)$$

Where, X indicates the input signal received by the algorithms (NLMS or NCMA) and T in (2) denotes complex conjugate.

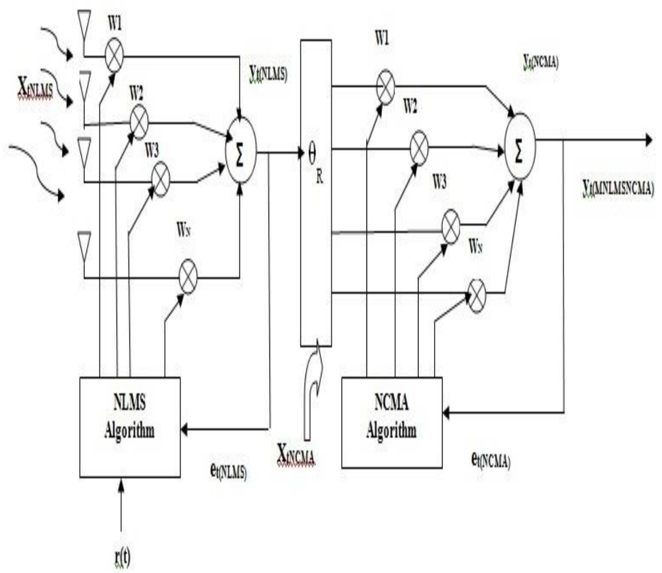


Figure 1 Proposed model of MNLMSNCMA

The signal X_t received by the antenna array is first processed by using NLMS algorithm, which generates an output represented as $y_{t(NLMS)}$. For every 'tth' iteration, the weight update of NLMS stage is given as;

$$W_{t+1(NLMS)} = W_t + \mu . e_{t(NLMS)} . X_{t(NLMS)} \quad (3)$$

Where, $e_{t(NLMS)}$ is error signal of NLMS stage given by $e_{t(NLMS)} = r(t) - y_{t(NLMS)}$

$y_{t(NLMS)} = W_{NLMS} . X_{t(NLMS)}$

$r(t)$ = desired signal,

$X_{t(NLMS)}$ = input to NLMS stage at 't'

μ = step size of adaptation.

After the processing of received signal by NLMS stage, NCMA processing will be proceeded. Input for the NCMA stage is generated in the following form;

$$X_{t(NCMA)} = A(\theta) . y_{t(NLMS)} \quad (4)$$

Where, $A(\theta)$ is array response vector or array image as given by (1) and $y_{t(NLMS)}$ is the output generated by NLMS stage.

In NCMA processing for every 'tth' iteration the weight update of NCMA stage is given as;

$$W_{t+1(NCMA)} = W_t + \mu . e_{t(NCMA)} . X_{t(NCMA)} \quad (5)$$

Where, $e_{t(NCMA)}$ is error signal of NCMA stage given by $e_{t(NCMA)} = y_{t(NCMA)} - \frac{y_{t(NCMA)}}{|y_{t(NCMA)}|}$

$y_{t(NCMA)} = W_{NCMA} . X_{t(NCMA)}$

To summarize, the processing steps in the proposed MNLMSNCMA are as follows;

- Perform adaptive non-blind beamforming using NLMS [equation(3)] ,
- Generate the input sequence for the NCMA processing [equation(4)],
- Perform adaptive blind beamforming using NCMA [equation(5)],
- Resultant would be the generation of optimum weight vector using MNLMSNCMA.

4. SIMULATION AND RESULTS

The proposed MNLMSNCMA algorithm's functionality was verified in Matlab R2014 environment and the synthesis of the proposed algorithm was performed using Precision plus synthesis tool. Simulation environment for MNLMSNCMA was created as depicted in table 1. Input for the processing considered was 16-point quadrature amplitude modulation (QAM) type with 50 samples. Figure 2 shows the output of the received signal without beamforming and figure 3 show the beamforming achieved using MNLMSNCMA. It can be observed from the figure 3 that the maximum gain or radiation was concentrated in the desired direction of 15^o.

Performance of the MNLMSNCMA is summarized in table 2 in comparison with LMSCMA. It can be observed that the array gain produced by MNLMSNCMA is (0.53db) only slight greater than the LMSCMA [4]. But the performance of MNLMSNCMA is significant in reducing the values of side lobe to -5db.

Parameters	**Values**
Digital Data Type	16-point QAM
Array elements	8
Spacing	ʎ/2
Number of Samples	50
Desired direction	15^o
Step size	.05

Table 1 Parameters for the simulation of MNLMSNCMA

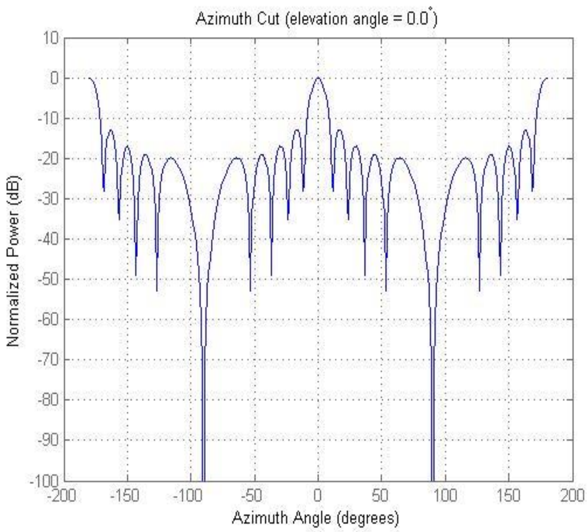


Figure 2 Array response without beamforming

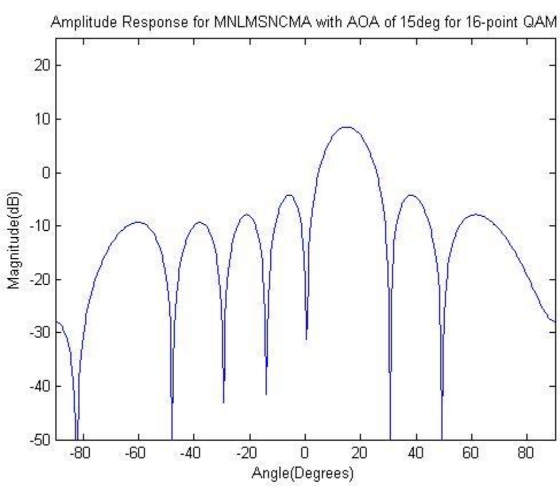


Figure 3 Array response after beamforming using MNLMSNCMA

Parameters	MNLMSNCMA	LMSCMA
Samples	*50*	*50*
Spacing	*$\lambda/2$*	*$\lambda/2$*
'θ' (deg)	*15*	*25*
Elements	*8*	*8*
Step size	*.05*	*.05*
Array gain (db)	***8.54***	***8.001***
Sidelobe (db)	*-5*	*1.8*

Table 2 Performance comparison of MNLMSNCMA and LMSCMA

Weights	MNLMSNCMA		NLMS	
	Optimal Weights	Initial Weights	Optimal Weights	Initial Weights
W1	**0.3256 - 0.0753i**	*-0.2342 + 0.1985i*	**0.4310 + 0.1183i**	*-0.0386 + 0.0154i*
W2	**0.2785 + 0.1847i**	*-0.3051 - 0.0337i*	**0.2103 + 0.3944i**	*-0.0377 - 0.0175i*
W3	**0.0572 + 0.3293i**	*-0.1852 - 0.2448i*	**-0.1420 + 0.4238i**	*-0.0132 - 0.0394i*
W4	**-0.1999 + 0.2678i**	*0.0506 - 0.3028i*	**-0.4054 + 0.1882i**	*0.0195 - 0.0367i*
W5	**-0.3319 + 0.0389i**	*0.2547 - 0.1714i*	**-0.4153 - 0.1652i**	*0.0400 - 0.0110i*
W6	**-0.2563 - 0.2144i**	*0.2995 + 0.0672i*	**-0.1654 - 0.4152i**	*0.0355 + 0.0215i*
W7	**-0.0204 - 0.3336i**	*0.1570 + 0.2638i*	**0.1880 - 0.4055i**	*0.0088 + 0.0406i*
W8	**0.2283 - 0.2441i**	*-0.0837 + 0.2953i*	**0.4238 - 0.1422i**	*-0.0234 + 0.0343i*

Table 3 Optimal and Initial Weight Vector values

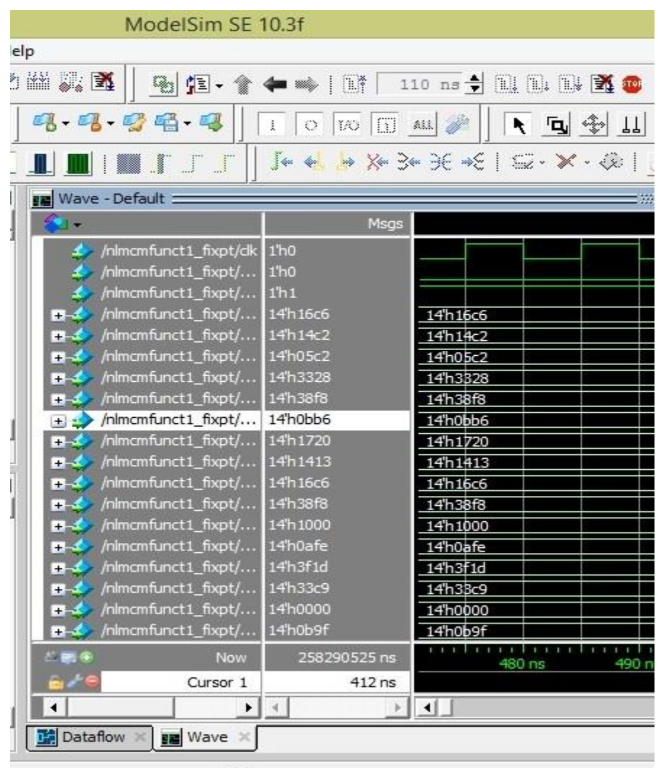
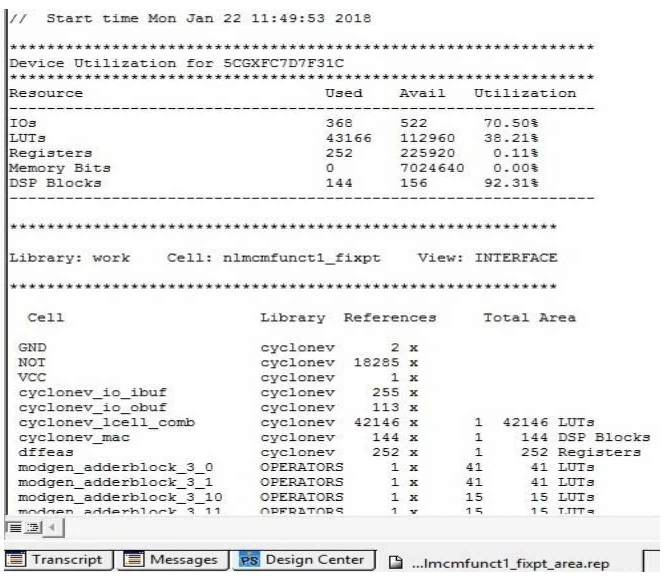


Figure 4 HDL Co-Simulation Results using Mentor Graphics Model Sim

For the synthesis of MNLMSNCMA, Verilog code of the proposed algorithm was generated using HDL coder of the Matlab. HDL coder will automatically generate synthesisable Verilog code along with the test bench [2]. Figure 4 shows the simulation of Verilog form of MNLMSNCMA along with test bench using Modelsim SE 10.3f of Mentor Graphics. Synthesis of MNLMSNCMA was performed using Precision plus synthesis tool for the Cyclone V family of device. Figure 5 and 6 shows the synthesis results of MNLMSNCMA.

Resources	Used	Available	Utilization (%)
IOs	368	522	70.50
LUTs	43166	112960	38.21
Registers	252	225920	0.11
DSP blocks	44	156	92.31

Table 4 Resource utilization of the device 5CGXFC7D7F31C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Device Utilization for 5CGXFC7D7F31C
**************************************************************
Resource                               Used    Avail    Utilization
--------------------------------------------------------------
IOs                                    368     522       70.50%
LUTs                                   43166   112960    38.21%
Registers                              252     225920     0.11%
Memory Bits                            0       7024640    0.00%
DSP Blocks                             144     156       92.31%
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Library: work    Cell: nlmcmfunct1_fixpt    View: INTERFACE

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  Cell                        Library  References     Total Area

 GND                          cyclonev       2 x
 NOT                          cyclonev   18285 x
 VCC                          cyclonev       1 x
 cyclonev_io_ibuf             cyclonev     255 x
 cyclonev_io_obuf             cyclonev     113 x
 cyclonev_lcell_comb          cyclonev   42146 x        1   42146 LUTs
 cyclonev_mac                 cyclonev     144 x        1     144 DSP Blocks
 dffeas                       cyclonev     252 x        1     252 Registers
 modgen_adderblock_3_0        OPERATORS      1 x       41      41 LUTs
 modgen_adderblock_3_1        OPERATORS      1 x       41      41 LUTs
 modgen_adderblock_3_10       OPERATORS      1 x       15      15 LUTs

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Figure 5. Synthesis report and Resource utilization of the device Cyclone V for MNLMSNCMA

5. CONCLUSION AND FUTURE WORK

For the growing challenges and complexities of wireless communication, adaptive beamforming will be one of the feasible solutions. The availability and development of advanced simulation and synthesis tools will be excellent means for prototyping of any complex system. In this paper we have developed a new kind of hybrid beamforming algorithm known as MNLMSNCMA for wireless communication applications such as SDR. From the simulation results it was evident that the performance of MNLMSNCMA was better compare to LMSCMA. In this work synthesis of MNLMSNCMA was also performed using Precision plus synthesis tool and the results are presented, which can be significant in development of single chip solution for beamformer. It was also observed that, the use of synthesis tool such as Mentor Graphics, it will also suggest the appropriate FPGA device to be used in case if any incompatibility found.

The extended work of this proposed work can be verification of the performance with other type of array structures like circular array. Single chip solution can be developed using advanced simulation and integration tools and the performance can be verified using real time data.

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