A Low Complex Modified Grey Wolf Optimization Model for OFDM Peak Power Reduction

R. S. Suriavel Rao [1], R. Menaka [2], and R. Alexciyaa Winslet [3]

[1] Department of Electronics and Communication Engineering
Dhanalakshmi Srinivasan College of Engineering, Coimbatore, India
suriavelraors@gmail.com

[2] Department of Electronics and Communication Engineering
Chennai Institute of Technology

[3] Department of Electronics and Communication Engineering
Karunya Institute of Technology and Sciences, Coimbatore, India

Abstract **–** Orthogonal frequency division multiplexing (OFDM) or multicarrier modulation is an essential signal processing technique in new generation wireless gadgets owing to its potential to support fast and spectrally efficient transmission. One of the major limitations of OFDM systems is the peak-to-average power ratio (PAPR) of transmit data. In this article, a novel meta heuristic algorithm called modified grey wolf optimizer is used to boost the computing performance of subcarrier phase factor search in the undisputed partial transmit sequence method. The proposed modified grey wolf optimizer (mGWO) has a balancing between exploration and exploitation phases while searching for peak power carriers and brings out a nearly optimal performance but with less number of iterations. The objective is to propose low complex computing algorithm without compromising the output quality. The simulation results of proposed mGWO-PTS model assure improvements around 20 to 25 percent from that of the comparative counterparts such as GWO-PTS, PSO-PTS, and etc.

Index Terms **—** BER, modified grey wolf optimizer, OFDM, PAPR.

I. INTRODUCTION

In the state of the art of wireless technology Orthogonal Frequency Division Multiplexing (OFDM) technique is a substantial signal processing algorithm due to its high speed compatibility, robustness to noise and appreciable spectral efficiency. One of the major limitations to employ OFDM in systems is the peak to average power ratio (PAPR) of the transmitted subcarriers. In this article, a novel modified Grey Wolf Optimizer (mGWO) is proposed to perform the phase factor search within the popular Partial Transmit Sequence technique such that the results are promising with low complex computations. Unlike any other search algorithm, the modified grey wolf optimizer rearranges the balancing between exploration and exploitation in searching of the best solution and brings out an optimal performance that has been generally achieved in many of its previous counterparts. The main goal of this proposed scheme is to achieve low complexity and a better PAPR minimization with a near or sub optimal data rate delivery across users. The results have proved that the modified grey wolf optimization algorithm used in phase factor search process yields improved performance than other combinations of PTS optimization algorithms.

Orthogonal Frequency Division Multiplexing is a widely used multi carrier modulation scheme by which data is loaded over multiple narrow sub carriers so that frequency diversity is achieved along with frequency flat fading to sub carriers. This provides spectral efficiency over single carrier transmission. Every subcarrier is modulated using one of the digital modulation schemes such as QPSK, 16QAM, and etc. at a low data rate. The choice of orthogonal sub carriers facilitates frequency flat fading thereby the noise impact is minimized to a larger extent. Thus, the SNR of transmit signal increases which ensures little noise filtering process at the receiver end. OFDM is established on the very familiar technique called Frequency Division Multiplexing (FDM). In FDM different users are allotted separate dedicated frequency channels. Each channel in FDM is detached from the other user bands by a frequency guard band to avoid inter carrier interference (ICI) between adjacent channels. Idle channels lead to spectrum wastage in case of FDM. The OFDM scheme differs from conventional FDM in many interrelated ways which are as mentioned below:

- Different subcarriers convey the different data blocks.
- Subcarriers are symmetrical to each other.

Submitted On: October 27, 2020
Accepted On: January 18, 2021

https://doi.org/10.47037/2020.ACES.J.360305

- Guard bands are added to every subcarrier to confine the channel in order to eliminate spectral leakage which causes Inter-Symbol Interference (ISI).
- Spectra are used efficiently by allowing overlap across successive sub channels or sub carriers.
- System is protected against co-channel interference and parasitic noise.
- Addition of Cyclic Prefix (CP) eliminates inter-symbol interference and inter carrier interference.
- It uses IFFT to enforce multicarrier modulation.
- Cancels any channel which is affected by frequency selective fading.
- Each sub-channel has low data rate so that the symbol duration is large thereby frequency flat fading occurs.

II. THE PEAK TO AVERAGE POWER RATIO

The channel variations in an Orthogonal Frequency Division Multiplexing signals may experience higher peak power values in the time field as several number of subcarriers are involved. These subcarriers are created using the famous Inverse Fast Fourier transform (IFFT) scheme. In a wireless transmitter one of the major challenges is to have linear power amplification. If power peaking occurs among subcarriers cross over distortion is induced. This is nothing but noise addition leading to distort the amplitude of the modulated carriers and hence data is lost. Another point is that PAPR leads to voltage surge to a considerable extent in the uplink which affects the constraint of battery power control in a mobile or portable device.

As it is mentioned earlier the PAPR is mathematically expressed as:

$$PAPR_{db} = 10\ log\left(\frac{max\ [x(t)x^*(t)]}{E\ [x(t)x^*(t)]}\right), \qquad (1)$$

where, the component $\left(\frac{max\ [x(t)x^*(t)]}{E\ [x(t)x^*(t)]}\right)$ represents the peak to mean power ratio of an instantaneous OFDM signal $x(t)$. In general, an OFDM symbol contains complex tones which are evenly spaced in the frequency domain in orthogonal multiples of $x(t) = e^{j2\pi ft}$.

At period $t = T$, the signal's peak value,

$$max[x(t)x^*(t)] = max\left[e^{j2\pi ft}e^{-j2\pi ft}\right] = max[e^0] = 1. \qquad (2)$$

The signal's mean squared value,

$$E[x(t)x^*(t)] = E(e^{j2\pi ft}e^{-j2\pi ft}) = 1. \qquad (3)$$

Using results of equations (1) and (2) the resultant PAPR is 0 dB. This means there is no peaking of power or it means that the peak power equals average power and hence no noise. Similar to the above equations, an OFDM signal is also expressed by including all the complex tones which are evenly spaced in the frequency domain as $x(t) = e^{j2\pi ft}$. It is well known that the time domain representation of OFDM signal is done by summing K complex tones spaced apart by 90 degrees from each other. The following equation defines it as a simple function $x(t)$ in terms of amplitude a_k and complex phase $e^{\frac{j2\pi kt}{T}}$:

$$x(t) = \sum_0^{K-1} a_k e^{\frac{j2\pi kt}{T}}. \qquad (4)$$

To make it simple, let us assume $a_k = 1$ for any k value. In this case, the signal's peak value is:

$$\begin{aligned} &max[x(t)x^*(t)] \\ &= max\left[\sum_{k=0}^{K-1} a_k \left(e^{\frac{j2\pi kt}{T}}\right) \sum_{k=0}^{K-1} a_k^* \left(e^{\frac{-j2\pi kt}{T}}\right)\right] \\ &= max\left[a_k a_k^* \sum_{k=0}^{K-1}\sum_{k=0}^{K-1} e^{\frac{j2\pi kt}{T}} e^{\frac{-j2\pi kt}{T}}\right] = 1. \end{aligned} \qquad (5)$$

The signal's mean square value is,

$$\begin{aligned} E[x(t)x^*(t)] &= E\left[\sum_{k=0}^{K-1} a_k\ e^{\frac{j2\pi kt}{T}} \sum_{k=0}^{K-1} a_k^* \left(e^{\frac{-j2\pi kt}{T}}\right)\right], \\ &= E\left[a_k\ a_k^* \sum_{k=0}^{K-1}\sum_{k=0}^{K-1} e^{\frac{j2\pi kt}{T}} e^{\frac{-j2\pi kt}{T}}\right] = 1. \end{aligned} \qquad (6)$$

Thus, if the subcarriers are modulated using same type of modulation, the PAPR is 0 dB, making the transmission noise free. It is important to notice that the IFFT operation is responsible to produce orthogonal subcarriers. Each subcarrier is loaded with a set of data by a suitable modulation scheme, for which an adaptive modulation or bit loading or power allocation scheme is employed. As it is known modulation is the process of converting a low frequency information bearing signal into a high frequency signal. Equation (6) is nothing but the autocorrelation of signal x(t). The Fourier transform of autocorrelation of x(t) gives out the Welch power spectral density which means the power distribution across a given frequency band. Welch spectrum helps an user to identify the signal strength of each subcarrier. At receiver end, Welch spectrum is used to provide the channel state information (CSI) which means the channel variations due to fading as it is a mobile wireless channel. In channel estimation process there are three approaches involved. A part of the CSI shall be sent back to the transmitter from receiver and vice versa so that it becomes a semi blind approach. In blind approach, no CSI is used. In data aided approach a cyclic redundancy check (CRC) or side information (SI) is used for signal detection and estimation at the receiver.

III. METAHEURISTICS IN MODIFIED GREY WOLF ALGORITHM

In recent years, the swarm intelligence model of animals is preferred for multi objective combinatorial optimization. The grey wolf algorithm is preferred as one of the most encouraging problem solving technique for encountering real time big data applications having large number of computations. The joint effort among fish, birds, flies and herd of animals to look for food and survival by planning a wise structure is known as swarm intelligence (SI). In order to handle nonlinear and combinatorial optimization problems, a huge amount of computing is needed. This results in system complexity and increased processing time to find out the best minima or maxima of a local or global search. There are numerous computing models developed by mimicking the swarm intelligence of various living organisms such as insect, wolf, bumble bees, winged animals, birds, fish, bat, fruit fly, fire fly, dragon fly, whales and etc. The Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Firefly Algorithm (FFA), Artificial Bee Colony (ABC) algorithm, Spider Monkey Optimizer (SMO), Whale Optimization (WO), African Buffalo Optimization (ABO), and Grey Wolf Optimizer (GWO) are some of the popular swarm intelligent algorithms which had proved that they are capable of solving industrial and research related optimization problems.

In the process of attaining computational intelligence, it is interesting to note that the choice of any search and optimization algorithm results in a similar statistical performance as proposed by the No Free Lunch (NFL) theorem. This theorem states that no free lunch is possible without a cost. The quality of any search problem has its cost. As the quality grows up the computations do grow. The Grey Wolf Optimizer (GWO) depends on administration and progression approach to hunt a prey. GWO algorithm is a new addendum to the group of swarm insight based metaheuristics. In the group of swarm intelligence based computing, GWO is the main approach which depends on a team coordinated hunting behaviour. The GWO calculation is a straight forward population based calculation which reproduces the authority and social conduct of the grey wolves to prey.

IV. RELATED WORKS

Article [1] uses a new swarm intelligence named the fireworks algorithm (FWA) to reduce PAPR while achieving a low computational complexity in MIMO-OFDM system. It reduces the phase factor search complexity of PTS algorithm while maintaining the desired PAPR optimization accuracy. Paper [2] projects innumerable algorithms to cut down the computational complexity along with PAPR. This is achieved by inculcating partial transmit sequences (PTS) method, variable to variable crossover in Cuckoo search algorithm (CSA) and also a combination of two methods. Thus, providing a better PAPR function than GA-PTS with adjacent partition and with pseudo-random partition. Study from [3] reveals an efficient PTS approach on particle swarm optimization to attain reduced PAPR and computational complexity wherein the proposed method expeditiously searches for the optimum combination of section rotation factors to decrease the procedural complexness.

Paper [4] deals with solution for rigorous hunt over the entire phase search which lead to high computing complexity. A less optimum PTS method is demonstrated upon the self-adaptive multi-population differential evolution algorithm (SAMDE) to find high quality resolutions with low computational cost by acquiring each sub-population of individuals over consequent generations.

Research in [5] applies SLM with ABC algorithm in PAPR reduction of MIMO-OFDM System. Also, artificial bee colony (ABC) algorithm, Modified ABC and parallel ABC (P-ABC) for SLM scheme are proposed which gives better PAPR reduction performance with less complexity. This proposed algorithm is giving better PAPR reduction and bit error rate (BER) performances with less complexity.

Article [6] samples various Algorithms on PAPR Reduction in OFDM System. Lately a sub optimal scheme which is based on artificial bee colony (ABC) algorithm is projected to hunt the better phase factors which also offer efficient PAPR reduction in OFDM system with less complexity. Information regarding optimal phase set is transmitted as side information which reduces the overall bandwidth efficiency. This problem is solved in paper [7] by adjoining PTS and GA in mapping scheme. Thus, leads to lower computations, increases the effective searching of function parameters and reduces the number of searches, to find the optimum phase factors. Though wavelet packet modulation has a merit of flexibility and modular implementation capability, it sustains high PAPR which extends signal distortion.

A new technique on biogeography based optimization is enhanced to a better level named generalized oppositional biogeography based optimization is exploited in the OFDM system to reduce PAPR and PTS searching complexity. By combining these two techniques in [8] the result exceeded the original algorithm prospects. In article [9], another PTS scheme has been developed so as to descent the PAPR by choosing the ideal stage factor by means of a versatile ABC optimization process. It can diminish the computational involution for bigger PTS sub blocks and offers lower PAPR in the meantime. Bat algorithm, when used for optimization the of sub-carrier phase it suffers from local optimum and low convergence accuracy. In paper [10] the velocity formula is updated so as to achieve convergence speed and speed while nullifying premature convergence. By implementing this improved algorithm in CO-OFDM PAPR is reduced by 5.48 dB and also searching ability and accuracy is amplified. The suggested algorithmic rule enhances the Peak to Average Power Reduction than using other selective mapping algorithms, Genetic and Quantum evolutionary.

Moreover, the suggested algorithmic rule meets faster than the quantum evolutionary and genetic algorithms. PTS selection is highly complex and the Computational Complexity is huge when all the subcarriers are transmitted in the OFDM system. Paper [11] applies a novel method named PTS selection, a modified chaos clone shuffled frog leaping algorithm (MCCSFLA), it's based on the chaos theory. This algorithm can converge to the global optimum, achieves better PAPR reduction, and converges faster. The impact of OFDM IFFT/FFT computational complexity in [12] is treated well with new approaches in the FPGA implementation context.

V. PROPOSED MGWO-PTS MODEL

The block diagram of the proposed model using mGWO-PTS is shown in Fig. 1. Grey Wolf belongs to the family of Canidae forming the apex position in the family of predators. Grey wolves almost live in a pack of size from 5 to 12 on an average.

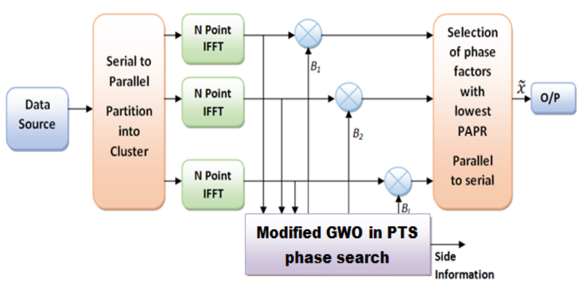

Fig. 1. Block diagram of the proposed model using mGWO-PTS.

The pack has alpha, beta, delta and omega wolves. Alpha leads the pack whereas others follow it. The betas are either female or male. Either the male or female can be the most effective nominee in the Alpha level, by the other case if the one in every alpha wolf are attacked terribly or passes away. The beta conveys alpha's command throughout the pack and it offers the feedback to an alpha wolf. The last out ranking grey wolf is omega. The Omega represents the character of the whipping boy The Omegas constantly resist all the opposite commanding wolves. The final wolves are also allowed to eat.

They must appear the form of Omega and is not a very important individual inside pack, it is determined that total pack face in internal fighting issues other case of missing the omega. It will often exhibit brutality and annoyance of all the wolves by the Omega. It always satisfies the complete maintenance and packing the dominance structure. In few conditions the omega will additionally be acting like baby sitters in the pack. A typical hunting scenario is shown in Fig. 2.

The behavior of grey wolves is categorized as follows.

- Sensing, Chasing, Tracking, and Approaching the prey.
- Encircling, Provoking, Pursuing the prey until it stops moving.
- Attacking and killing the prey.

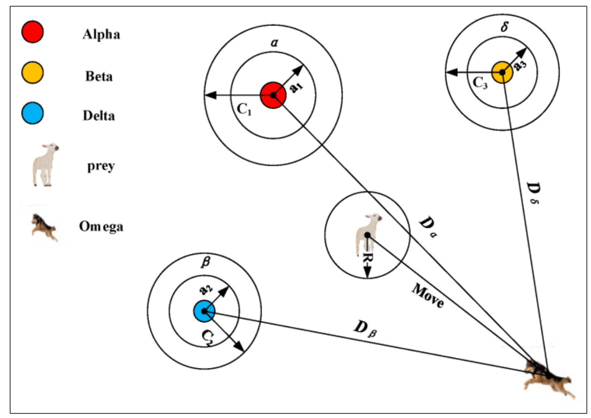

Fig. 2. Grey wolves hunting scheme (source: https:// www.google.com).

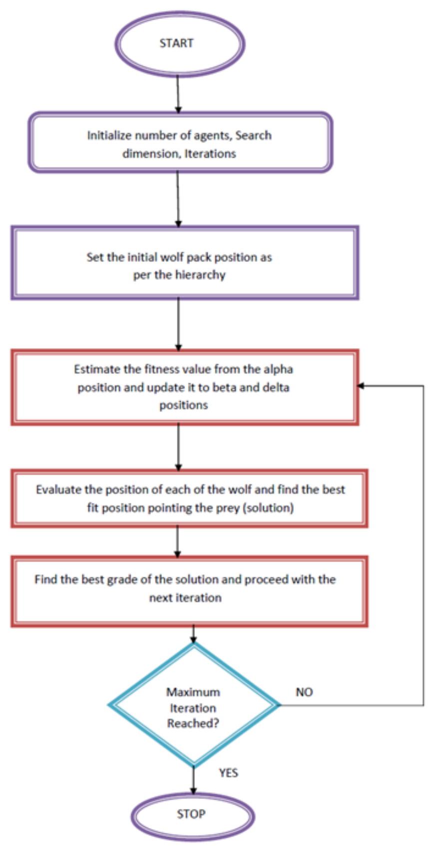

Fig. 3. Flow chart of mGWO algorithm.

Figure 3 clearly illustrates the sequential process flow of the modified GWO algorithm. As it is verified from the literature studies, the convergence of mGWO is faster and efficient compared to its former version the grey wolf algorithm. In this case, the exploration takes 70 percent effort whereas exploitation phase consumes 25 percent search effort, resulting in a non linear search. The proposed algorithm exhibits appreciable global convergence by avoiding local minima.

Equation (7) describes the linear search model of conventional grey wolf optimizer model in which both the exploration and exploitation phases of finding the minimum phase value occupy 50 percent effort respectively:

$$a = 2\left(1 - \frac{t}{T}\right). \tag{7}$$

From equation (8) it is evident that a squared search function is introduced by which the exploration of prey (solution) needs almost 70 percent search iterations just to locate the prey; and remaining 30 percent search effort is spent to zero in to the prey (solution):

$$a = 2\left(1 - \frac{t^2}{T^2}\right). \tag{8}$$

VI. RESULTS AND DISCUSSION

This section presents several results in support of the proposed method to find the minimum PAPR values with fast convergence.

Figure 4 illustrates the proposed mGWO tool box in which an optimum value of 0.998 is obtained with merely 200 iterations.

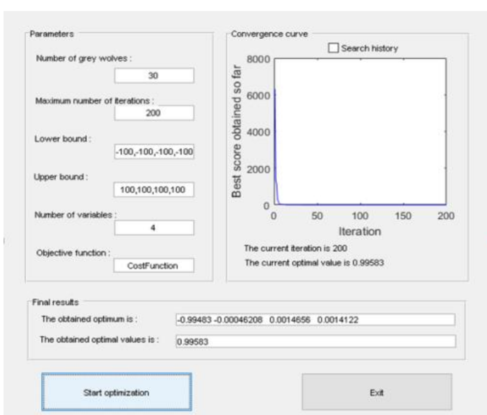

Fig. 4. Performance of mGWO at 200 iterations.

Figure 5 illustrates that the proposed mGWO converges to the minimum value with 280 iterations whereas conventional GWO takes 330 iterations. This ensures that the proposed mGWO saves computations by 15%.

Figure 6 compares the peak power reduction capacity of proposed method and other conventional methods. Proposed mGWO-OFDM exhibits low peak to average power at a low SNR of 14 dB.

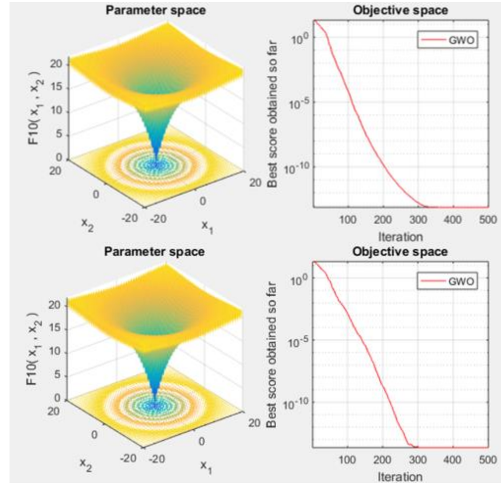

Fig. 5. GWO versus mGWO for 500 iterations.

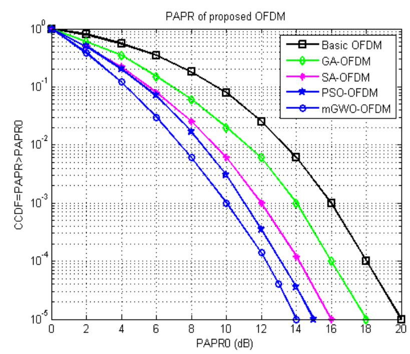

Fig. 6. PAPR of proposed method.

Figure 7 portrays the BER performance of proposed PTS based PAPR reduction by using proposed mGWO. At the lowest SNR of 10 dB, the proposed scheme exhibits a lowest BER of 10^{-5} whereas the error increases significantly in all other methods. The detailed BER pattern at SNR of 10 dB is depicted in Fig. 8.

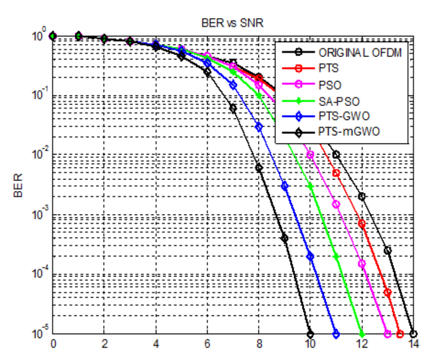

Fig. 7. BER performance of proposed PTS-mGWO.

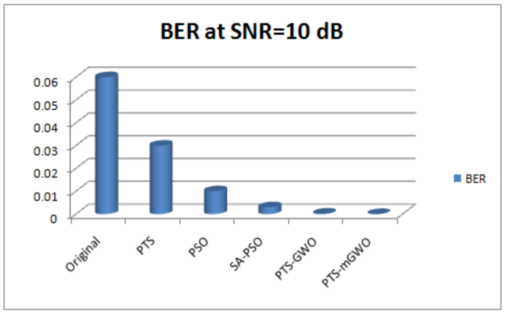

Fig. 8. BER performance of PTS-mGWO at SNR=10dB.

VII. CONCLUSION

The proposed work gives a better output for OFDM optimization and reduced PAPR values by the PTS method using the modified grey wolf algorithm. The modified GWO gets an earlier convergence when compared to the original GWO and also a reduced complexity is obtained in the results.

ACKNOWLEDGMENT

This article is neither financially supported nor sponsored by any government or non-government agencies.

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R. S. Suriavel Rao received Ph.D. degree in Information and Communication Engineering from Anna University Chennai. He received both Bachelor and Master Degrees in Electronics and Communication Engineering from M.S. University and Anna University respectively. He is currently serving in the capacity of Professor cum Research Consultant. He has expertise in ASIC design, Antenna and Communication system design as well. Currently he is working on IoT, AI, Deep/Machine learning techniques, and data science. He has vast quantity of teaching and research experiences. His areas of interest are OFDM optimization, WiMax technology, IoT, SoC Design, 5G Wireless Technology.

R. Menaka obtained her Ph.D. degree in Information and Communication Engineering from Anna University Chennai. She received Bachelor degree in Electronics and Communication Engineering from Madras University and Masters degree in Applied Electronics from College of Engineering, Guindy (Anna University). She is presently working as Professor in the Department of ECE, Chennai Institute of Technology. She has around 20 years of teaching experience. Her area of Interest includes Mobile Ad hoc Networks, Wireless Networks and Image & Signal Processing.

R. Alexciyaa Winslet received B.Tech. degree in Electronics and Communication Engineering from Karunya Institute of Technology and Sciences, Coimbatore. She is currently a Post Graduate Student with specialization in VLSI Design at Karunya Institute of Technology and Sciences. Her areas of interest include OFDM system optimization, IC Design using Verilog Coding, and fabrication.