

Non-Uniform search domain based Genetic algorithm for the optimization of real time FFT Processor architectures

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Abstract— This paper presents a GA for optimization of word length coefficients in a pipelined FFT processor. The algorithm optimizes memory and buses both at the I/O interfaces within the processor datapath. This provides a complex search space in which the algorithm needs balance optimization parameters against error. A special feature of the GA is the use of non-uniform operators which allow tuning the search to provide an optimal optimization with minimum number of generations. The paper describes the algorithm, the concept of non uniform operators through the mutation operation. The results show the effect of both uniform and non uniform sampling on the quality of the optimization, turbulence towards convergence, and the speed of convergence.

I. INTRODUCTION

MC-CDMA is one of the most attractive wireless receivers for broadband multimedia communication system which combines the advantages of OFDM (Orthogonal frequency division multiplexing) and CDMA to produce a spectrally efficient multi-user access system. The combined requirement for high performance and power is the critical design issue for these wireless systems. These systems need to have high performance in terms of smaller error at their outputs as they are operating in a varying environment like changing data rate and bit error rate along with changing bandwidth and other channel parameters such as delay spread. On the other hand, the portability requirement of these systems is mainly responsible for the need of low power architecture. It is therefore important to design these systems which can adapt their operations instead of being designed for the worst case scenario.

This paper presents a Genetic Algorithm for the optimization of word length for both data and coefficients in real time pipelined FFT processor architectures. The algorithm is specially tailored in order to optimize memory

and buses both at the input/output interfaces as well as internally within the processor datapath. This provides a complex search space in which the algorithm needs balance optimization parameters against error. A special feature of the GA is the use of non-uniform operators which allow tuning the search in order provide an optimal optimization with minimum number of generations. The paper describes the algorithm, the concept of non uniform operators through the mutation operation and provides results demonstrating the effect of both uniform and non uniform sampling on the quality of the optimization, turbulence towards convergence, and the speed of convergence.

The paper presents the analysis of the impact of word length optimization of fixed-point Fast Fourier Transform (FFT) coefficients on error using Genetic Algorithm (GA). The solutions found by the GA are then evaluated for power evaluation. GA is used in this optimization because it is a class of evolutionary algorithm that can be used for the discovery of near-optimal solutions to multi-modal problems. It makes use of population of solutions, enabling simultaneous discovery of multiple solutions. The work investigates the possibility to find a solution for the FFT coefficients which have optimum performance in terms of error and power consumption. A specific issue of concern in this research would be targeting on-chip optimization of a complete wireless MC-CDMA receiver.

II. APPLICATION DOMAIN

MC-CDMA receiver consists of two main blocks, an FFT block to demodulate the OFDM signals and a combiner block which equalizes the signal and separates out the coded users. The FFT processor is one of the blocks which contribute the most power consumption [1]. Power consumption of FFT processor depends on the size of the word length of the data and the FFT coefficients [2]. The larger word length means the higher power consumption which is due to more switching activities [3]. On the other

hand, larger word length means less error and higher signal to noise ratio (SNR). Therefore, it is highly desirable to design an FFT processor which is optimized in terms of error and power consumption. Consequently, the performance of the MC-CDMA receiver will be partly optimized. The optimization of equalizer coefficients in the combiner block will complete the optimization of the whole MC-CDMA receiver.

The FFT processor used in this work is based on the radix-4 single-path delay commutator (R4SDC) architecture proposed by the authors in [4]. This architecture is chosen because it has been used recently in building the largest ever single chip pipelined FFT processor for HDTV application [5] and has tremendous saving in hardware and power consumption for real-time applications [6]. Fig. 1 shows the block diagram of a 16-point FFT based on this architecture.

Real time adaptation is desirable for such a processor as the receiver will be required to adapt (by triggering the GA) every time the position changes such as indoor/outdoor, stationary/moving, etc.

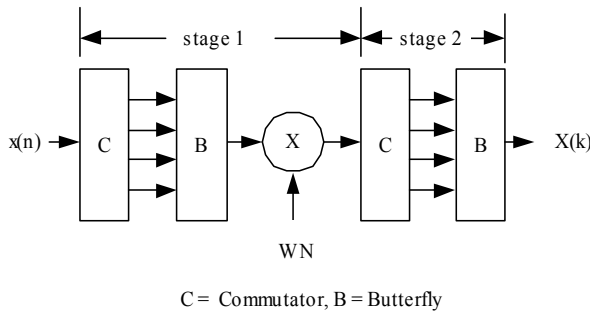


Figure 1. Block diagram of a 16-point R4SDC pipelined FFT.

III. GENETIC ALGORITHM

A. System Description

Fig. 2 shows the block diagram of the targeted system which consists of three main blocks namely, memory, microprocessor, and reconfigurable MC-CDMA receiver.

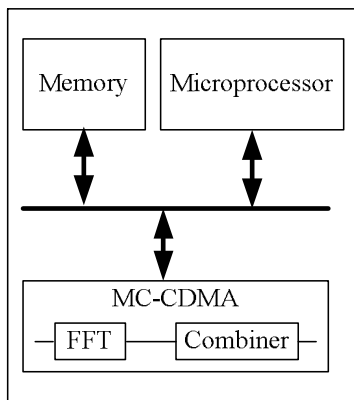


Figure 2. Block diagram of the system.

The choice of the microprocessor is an OpenRISC 1200. This is a common MIPS-based architecture which has been used for a spectrum of implementations at a variety of price/performance levels for a range of industrial telecommunication applications [8]. The main function of the microprocessor is executing the GA program to find solutions of optimized FFT coefficients for a specific word length. The memory is used to store the GA program and the chromosomes.

The GA used in this work is a standard GA procedure [7]. Fig. 3 illustrates the flow chart of the execution of the GA on the microprocessor.

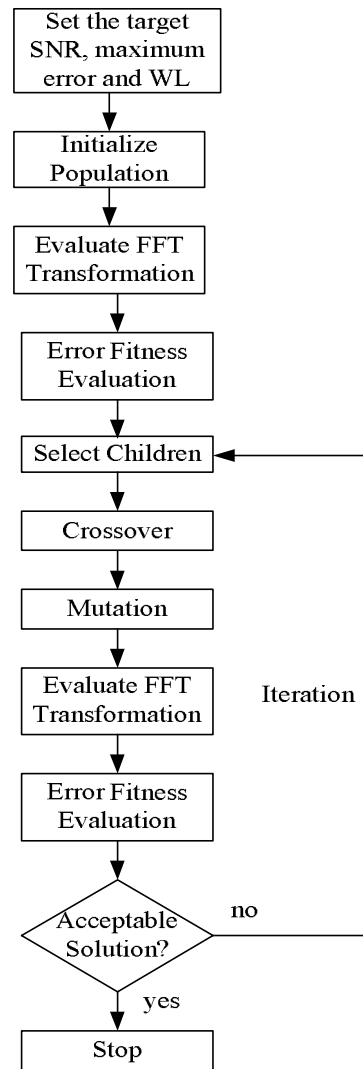


Figure 3. Flow chart of the GA.

The GA algorithm begins with specifying the target SNR, maximum error allowed and word length. In practice, these parameters may change in real-time depending on the conditions of the environment like delay spread, SNR, bandwidth and bit error rate where the MC-CDMA receiver

is situated. Next, an initial population is created by truncating and applying random process to the initial representation of the chromosome as described in sub-section B. Calculation of FFT transformation and error fitness evaluation are then performed on each individual in the initial population as explained in details in sub-section D. A children population is produced using the roulette wheel selection. The children are then evaluated for their error fitness after the crossover and mutation operations. If a solution in the new population has lower error than the maximum error allowed, it is considered as an acceptable solution. The search continues until a number of acceptable solutions are found or the maximum number of generations is reached. In this work, the maximum number of generations is set to 200.

B. Chromosome

Fig. 4 displays the chromosome representation of the coefficients for the whole block of FFT processor. Each stage of the chromosome contains 2 fields of information: coefficients and control. The coefficients field stores the real and imaginary parts of the FFT coefficients (twiddle factor), WN and data coefficients, $x(n)$. First stage is the only stage which has both WN and $x(n)$ coefficients as shown in Fig. 1. The other stages only have the FFT coefficients except for the final stage. All the coefficients are initially 16 bits in length. The control bits are used to select either FFT coefficients optimization or data optimization or both of these.

The length of the chromosome depends on the size of the FFT. For an example, a 16-point FFT will consist of 16 FFT coefficients and 16 data coefficients in the first stage. The initial data and FFT coefficients are obtained from the MATLAB FFT procedure and then are represented as 16-bit numbers. A population size of 50 is chosen through experimentation as it provides sufficient solution diversity.

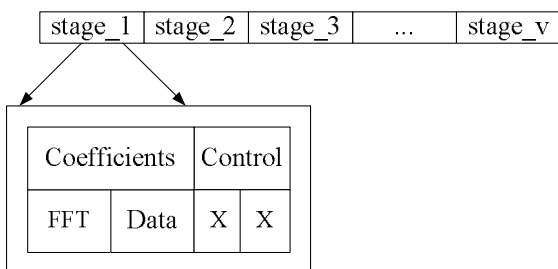


Figure 4. Chromosome structure.

C. Genetic Operators

The genetic operators used in this work are extracted from standard GA procedure which includes selection using roulette wheel, crossovers and mutation [7]. In this work, the rates for crossovers and mutation are chosen as 90% and 10% respectively. This was chosen through experimentation as it provides sufficient solution diversity.

D. Mutation Domain

Most of the solutions searching are done by the crossover operation. The need for mutation is to keep or introduce diversity in the population. In this work, the mutation domain initially set to $[-3,+3]$. This domain is varied from $[-1,+1]$ to $[-6,+6]$ throughout the work to investigate the effect on the performance of the GA.

E. Error Fitness Evaluation

Error fitness evaluation for each solution obtained by the GA is carried out as follows. The first step is to determine the corresponding SNR values for all the FFT outputs using the formula in (1),

$$SNR = 10 \log_{10} \left[\frac{(R_{16})^2 + (I_{16})^2}{(R_{16} - R_{wl})^2 + (I_{16} - I_{wl})^2} \right] \quad (1)$$

R_{16} , I_{16} , R_{wl} and I_{wl} are the real and imaginary parts of the FFT output before and after optimization respectively. Next, each SNR(k) value is compared with a target, SNRT. If the former is lower than the latter, an error will be calculated as the difference between the latter and the former. Finally, the total error is calculated by summing all the individual errors.

A solution which has a total error less than the maximum error allowed is considered as an acceptable solution. The maximum allowed error is determined using the lowest error either from the truncated or rounded solutions and the gain. The rounded and truncated solutions are the solutions which are obtained by simply rounding and truncating the FFT coefficients respectively.

F. Power Fitness Evaluation

Power fitness evaluation is carried out by first placing the solution of the FFT coefficients obtained either by the GA or rounding into the FFT hardware verilog code. Next, this code is synthesized using 0.18 μ CMOS library technology at 1.8V and 100 MHz clock frequency. This will provide a netlist of the FFT hardware which in turn will be simulated. If the netlist simulation results are similar to the register transfer level (RTL) simulation results, then finally the power analysis is performed using Synopsis Design Power tools.

IV. RESULTS

In this work, the optimizations were done on the 64-point FFT coefficients in the first and second stage individually. The results of both cases show similar trends in terms of error and power consumption.

Table 1 lists three different types of solutions which are obtained as follows: rounding, truncation and GA for optimizing in the second stage from 15 to 8 bits for the SNRT of 60 dB. The GA results are the best results obtained after four runs. The table shows that as the word length increases, the error decreases for all the three types of solutions. For the optimization at 8-bit word length, the lowest error from the first two solutions is 1164 dB. In this experiment, the desired gain is chosen as 1.5 dB. For a 64-point FFT, this requires a difference of 96 dB from the

lowest error. As a result, the maximum error allowed is set as 1068 dB.

TABLE I. ERROR FITNESS FOR ROUNDED, TRUNCATED AND GA SOLUTIONS

WL	Error (dB) Rounded Solution	Error (dB) Truncated Solution	Error (dB) GA solutions
8	1168	1164	1062, 1067, 1070, 1080, 1090, 1100, 1110, 1123, 1133, 1154
9	774	769	704, 710, 720, 730, 740, 752, 760
10	367	375	332, 340, 350, 361
11	23	46	7, 14, 20
12	1	1	0
13	0	0	0
14	0	0	0
15	0	0	0

Fig. 5 shows the best performance of the GA from four runs for three different mutation domains; [-1,+1], [-3,+3] and [-6,+6]. The figure shows that the GA with a mutation domain of [-1,+1] found the best solution with an error of 1070 dB after 160 generations and converges with very minimum fluctuations. The GA with a mutation domain of [-3,+3] can find solutions with errors of 1062 dB and 1067 dB in the 87th and 47th generations respectively. This implies that the solutions obtained by the GA are 1.5 dB better in SNR than the other two types of solutions. It also shows that with this mutation domain, the GA can find the solutions faster than two other domains. The GA with the mutation domain of [-6,+6] found the solution after 190 generations. It converges with most number of fluctuations.

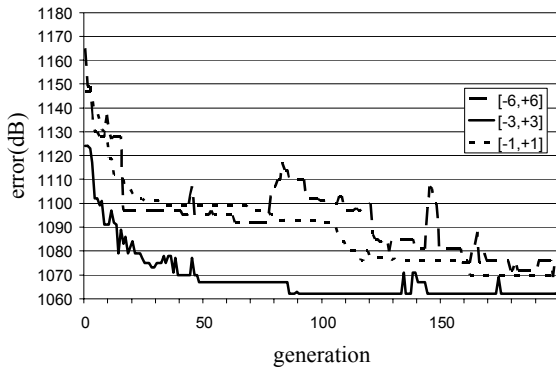


Figure 5. GA performance with uniform mutation domains

Fig. 6 displays the best performance of the GA with two different non-uniform mutations domains; [-1,+2] and [-1,+4] after four runs. The results show that for both domains, the best solutions have errors of 1069 dB. The former found the solution after 80 generations and the latter found after 190 generations. The figure also shows that as in the case of the uniform mutation domain, the GA with smaller mutation converges with least number of fluctuations.

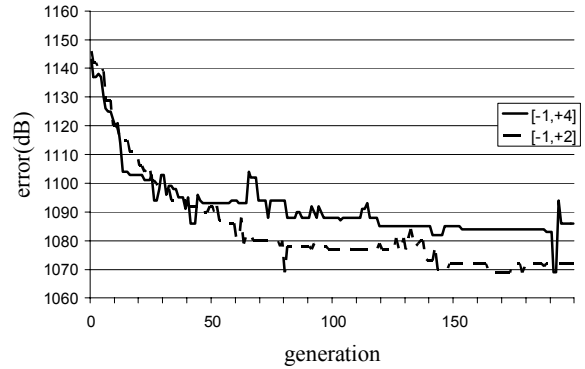


Figure 6. GA performance with non-uniform mutation domains

Table 2 displays the figures for switching activity and power consumption for the first two types of solutions. The switching activity figure is calculated based on the hamming distance within FFT coefficients whereas the power figure is obtained by placing both solutions in the FFT hardware design followed by power analysis as explained in details in sub-section F. The results show that as the word length increases, the switching activity also increases which in turn increases the power consumption for the two types of solutions. The lowest figure is used as the limit in power consumption evaluation. By comparing the figures listed in Table 1 and 2, it can be shown that these two figures conflict with each other as word length increases.

TABLE II. POWER FITNESS FOR ROUNDED AND TRUNCATED SOLUTIONS

WL	Rounded Solution	Power (mW)	Truncated Solution	Power (mW)
8	94	203	90	203
9	102	205	102	205
10	114	205	116	205
11	120	206	128	207
12	126	206	140	208
13	140	208	152	210
14	150	209	166	211
15	162	209	178	211

Table 3 switching activity and power consumption figures for the best solutions obtained by the GA with the lowest error in the above optimization. The results show that switching activity figures of the GA solutions are closer to the other two types of solutions.

TABLE III. POWER FITNESS FOR THE BEST SOLUTIONS FOUND BY GA

WL	Error (dB)	Switching Activity	Power (mW)
8	1062	86	202
9	704	110	205
10	332	110	205
11	7	124	207

V. CONCLUSION

The paper has presented a genetic algorithm with non-uniform search capability for the optimization of all parameters of a pipelined FFT processor. The non-uniform search operates on real number values of coefficients and data with the aim of providing best optimization with the minimum number of generations. We show that different domain ranges have an impact on the speed of the search, its quality and the turbulence as the GA converges towards a given solution. Although, we show the GA using the FFT example, it can be adapted for most DSP tasks requiring real time operation.

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