Multi objective inclined planes system optimization algorithm for VLSI Circuit Partitioning

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Abstract :

In this paper multi objective optimization problem for partitioning process of VLSI circuit optimization is solved using IPO algorithm. The methodology used in this paper is based upon the dynamic of sliding motion along a frictionless inclined plane. In this work, modules and elements of the circuit are divided into two smaller parts (components) in order to minimize the cutsize and area imbalance. The algorithm is implemented to test real case study named RC6 block cipher circuit. The multi objective IPO algorithm (MOIPO) will give better results in comparison with the multi objective particle swarm optimization algorithm (MOPSO) with the same evaluation function.

Keywords: MOIPO, Optimization algorithm, Partitioning, Cutsize, Area imbalance.

Submission date : 01 , 11 , 2017

Acceptance date : 03 , 02 , 2018

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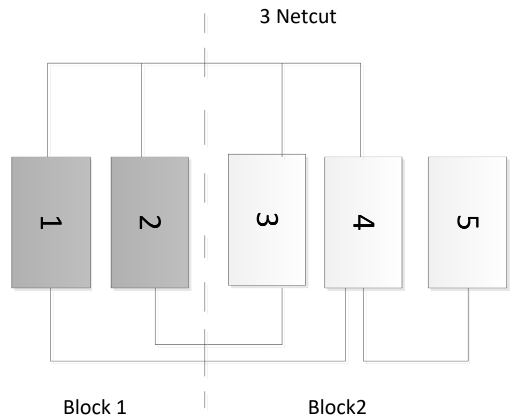
1. Introduction

The term VLSI, in the world of digital IC design refers to very large scale integration. Integration means accommodating the components and elements of chip in a limited and specified size bed so that optimal use of spaces and facilities. Partitioning process is the first step in physical design. In this step, modules and elements of the circuit are divided into a collection of smaller parts (components). Since, partitioning is a NP-hard problem and so this problem cannot be effectively solved by exact methods. In recent years there has been a great interest in evolutionary algorithms to solve partitioning optimization problems in VLSI circuits. References [1,2,3] have proposed the genetic algorithm for VLSI circuit partitioning by considering area minimization and number of cuts. Reference [4] has proposed hybrid optimization technique for circuit partitioning using PSO and Genetic Algorithm to reduce mincut. In [5] a method based on hybrid multi-objective PSO algorithm with local search strategy was introduced that focuses on getting better values of cutsize and circuit delay. In this paper, an effective multi-objective partitioning algorithm, based on inclined planes system optimization algorithm, called MOIPO, is presented to solve the VLSI partitioning. The goal is minimizing the cutsize and area imbalance .

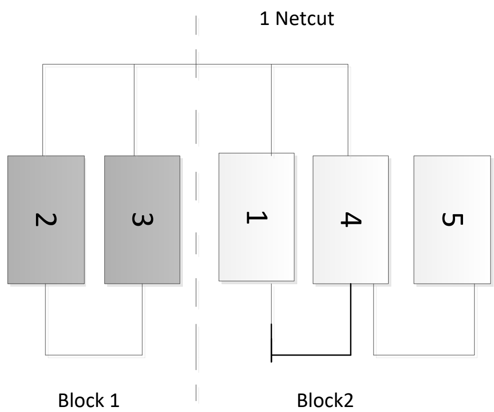
This paper consists of seven parts. Section 2 describes the problem. Section 3 describes Optimization objective function. Section 4, explains inclined planes system optimization algorithm and multi-objective IPO (MOIPO). The ball encoding for solving the partitioning problem using IPO algorithm is introduced in Section 5. Simulation results are shown in section 6 and conclusion is in Section 7.

2. Problem definition

The VLSI circuit partitioning problem is modeled as graph. Circuit cells represented as nodes and the connections between the two different parts as edges. The partitioning algorithm separates the circuit cells (nodes) into two disjoint parts, so that the sum of cell areas in each part is equal and the number of connections (cutsize) between the two different partitions is minimized. As a sample of bipartitioning, the circuit with five nodes and four nets is represented in figure 1.



a) Before swap 3 Nets Cut



b) After swap 1 Nets Cut.

Fig. 1. Circuit bipartitioning overview [6]

3. Objective Function

All required "Styles" are predefined, and so there is no need to define a new one. Just select the appropriate style with respect to different sections of a paper.
The quality of a VLSI circuit partitioning is usually measured by two cost terms, namely the cutsize, and area imbalance.

Cutsize: In VLSI circuit partitioning, modules and elements of the circuit are divided into two smaller parts (components) which the number of interconnections between two partitions is defined as cutsize. The goal is to minimize number of interconnections between two partitions. The total cutsize, C, can be expressed as:

$$C = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} \qquad (1)$$

C is the total cost of the cuts; and C_{ij} is the cost of an edge that connect nodes in partition i and partition j.

Area imbalance: Another goal for optimization is to reduce the area differences between two partitions. In fact, the sum of cells in two partitions will be equal.

$$\sum_{i=1}^{m} M_i = \sum_{j=1}^{n} N_j \quad (2)$$

m, n are the number of nodes in partition i and partition j, respectively. M_i and N_j are the total area of the partition i and partition j, respectively.

4. Multi-objective Inclined planes system optimization (IPO) Algorithm

IPO algorithm is inspired by the dynamic motion of spherical objects along frictionless inclined plane. In IPO, some tiny balls (agents of the algorithm) search the problem space to find near optimal (here, minimum) solutions. The basic idea of IPO is to ascribe height to each agent, regarding to its objective function. These heights are estimations of the potential energy of each ball that should be converted to kinetic energy by assigning suitable acceleration. In fact, agents tend to lose their potential energy to reach the minimum points [7].

As shown in figure 2, balls accelerate and search the problem space for better solutions, iteratively.

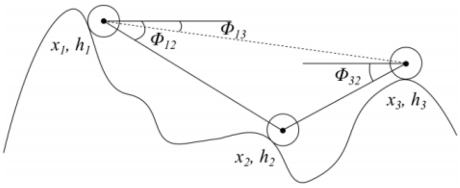


Fig. 2. An example of problem search space with three balls and estimated inclined planes [7]

Position, height and angles made with other balls, are three characteristics of each ball in the search space. The position of each ball is a possible solution in the problem space and their heights are acquired using a fitness function. Angles are calculated by crossing straight lines from center of ball to centers of other balls to estimate an inclined plane on which the ball is located.

In a system with N balls, the position of the i-th ball is specified by equation (3):

$$x_i = \left(x_i^1, \ldots, x_i^d, \ldots, x_i^n\right), \text{for } i = 1,2,\ldots,N \quad (3)$$

Where, x_i^d is the position of i-th ball in the d-th dimension in an n dimensional space. At a given time t, angle between the i-th ball and j-th one in dimension d, i.e.ation (4):, is computed using equ φ_{ij}^d

$$\varphi_{ij}^d(t) = \left(\tan^{-1}\left(\frac{f_j(t) - f_i(t)}{x_i^d(t) - x_j^d(t)} \right) \right), \quad (4)$$
$$\text{for } d = 1,\ldots,n \text{ and } i,j = 1,2,\ldots,N, i \neq j$$

In which, $f_i(t)$ is the height (value of objective function) for the i-th ball in time t. Because a specific ball tends moving toward the lowest heights on the inclined plane, only balls with lower heights (fitness) are used in acceleration calculating. The addition of these accelerations on various planes obtains the total acceleration of the ball. It is known from the Newton's second law:

$$\sum \vec{F} = m\vec{a} \quad (5)$$

The acceleration of a moving object on a frictionless inclined plane is shown in equation 6.

$$g = a * \sin(\varphi) \quad (6)$$

Where g is constant value of gravitational acceleration, and φ is the angle with respect to horizontal surface. The amplitude and direction of acceleration for the i-th ball at time t and in dimension d, is measured using equation 7:

$$a_i^d(t) = \sum_{j=1}^{N} U\left(f_j(t) - f_i(t)\right) . \sin\left(\varphi_{ij}^d(t)\right) \quad (7)$$

Where, $U(\cdot)$ is the Unit Step Function:

$$U(w) = \begin{cases} 1 & w \succ 0 \\ 0 & w \leq 0 \end{cases} \quad (8)$$

Finally, equation 9 is used to update the position of the balls:

$$\begin{aligned} x_i^d(t+1) = {} & k_1.rand_1.a_i^d(t).\Delta t^2 + \\ & k_2.rand_2.v_i^d(t).\Delta t + x_i^d(t) \end{aligned} \quad (9)$$

rand$_1$ and *rand*$_2$ are two random weights distributed uniformly on the interval [0,1]. $v_i^d(t)$ is the velocity of i-th ball in dimension d, at time t. to control the search process of algorithm, two essential parameters named k_1 and k_2 are used. These control parameters of IPO are defined as functions of time (t) by using equations (10) and (11):

$$k_1(t) = \frac{c_1}{1 + \exp\left(\left(t - shift_1\right) \times scale_1\right)} \quad (10)$$

$$k_2(t) = \frac{c_2}{1 + \exp\left(\left(t - shift_2\right) \times scale_2\right)} \quad (11)$$

Where c_1, c_2, $shift_1$, $shift_2$, $scale_1$ and $scale_2$ are constants which are determined for each function, experimentally.

$v_i^d(t)$ is shown in equation (12):

$$v_i^d(t) = \frac{x_{best}^d(t) - x_i^d(t)}{\Delta t} \quad (12)$$

In the above equation, x_{best}^d is used in numerator to determine the ball desire to reach the best position in any iteration. In fact, Equations (13) and (14) are adopted from the dynamic of motion with constant acceleration in classical mechanics:

$$\vec{x} = \frac{1}{2}\vec{a}.t^2 + \vec{v}_0.t + \vec{x}_0 \quad (13)$$

$$\vec{v} = \frac{\Delta \vec{x}}{\Delta t} \quad (14)$$

The main structure of the Inclined Planes optimization algorithm should be amended to use it in multi-objective problems. The essential steps of multi-objective IPO are as follows:

1- Initialize the population, a repository for non-dominated solutions and evaluation.
2- Separate non-dominated members and store them in the repository.
3- Generate hypercube of the objective space.
4- Each search agent moves on the basis of equations (9).
5- Update the IPO parameters.
6- Add non-dominated members of current population to the repository.
7- Delete dominated members from repository.
8- Delete additional members if the size of repository is more than the specified capacity.
9- End if the end conditions are established otherwise go back to step 3.

5. Ball encoding in IPO algorithm

Since there are only two parts for circuit, the binary-coded ball representation is adopted here so that its values of 1 and 0 can be employed to represent the partition of a component in the circuit. Considering a circuit with 8 nodes, that Nodes M1, M2, M4, and M8 are in partition 0 and Nodes M3, M5, M6, and M7 are in partition 1, so the gene values for nodes of partition 0 are fixed as zero and for nodes of partition 1 are fixed as one.

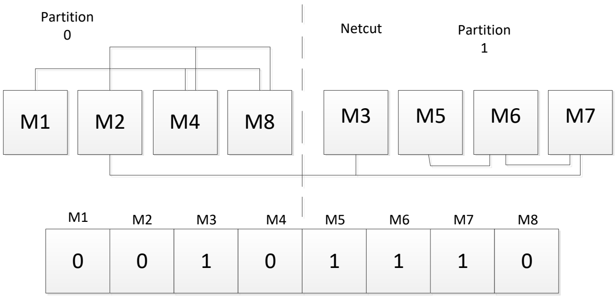


Fig. 3. Representation of ball for bipartitioning [8]

For more explanation, the algorithm takes 00101110 and 00100111, as a position of two balls and find the height of them according to the fitness function (here equation 1 and 2). Then the amount of angel, velocity and acceleration of the balls are calculated and position of the balls updates.

6. Simulation results

The proposed algorithm is implemented on an AMD with 4GB memory using MATLAB (R2011a) with windows operating system. For numerical experimentation, the RC6 block cipher is considered.

6.1. A case study of RC6 Block Cipher

Symmetric block ciphers are usually used in a wide range of applications from e-mail messages to ATM's to secure distribution of Internet contents [9].RC6 is a block cipher of encryption algorithms. It is an extension of RC5. According to the requirements of the AES (Advance Encryption standard), a block cipher must handle 128-bit input/output blocks. RC6 is designed to use four 32-bit registers [9]. The hardware-based implementation of AES algorithm is required because it can be more secure and consumes less power than software implementation [10]. RC6 works with four w-bit registers A; B; C; D which contain the initial input plain text as well as the output cipher text at the end of encryption. The first byte of plaintext or cipher text is placed in the least-significant byte of A; the last byte of plaintext or cipher text is placed into the most-significant byte of D [9]. The block structure for encryption/decryption circuit is depicted in Figure 4.

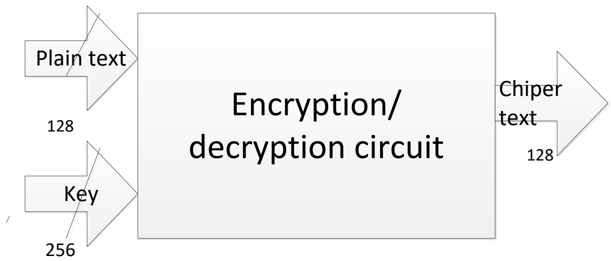


Fig. 4. The block structure for encryption/decryption circuit [11]

Encryption and decryption circuits consist of three components:
1) One module for subkeys generation
2) One for encryption/ decryption for each round
3) Command structure for encryption/decryption.

The circuit structure with every block is depicted in figure 5. In encryption and decryption process, Subkeys generation module for RC6 algorithm is alike. Subkeys generation module is part of the command structure for encryption/decryption [11].

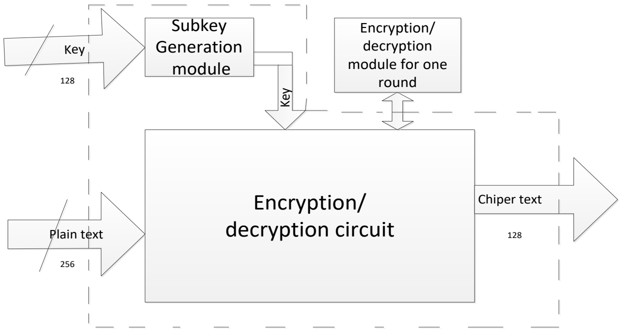


Fig. 5. The encryption/decryption circuit [11]

The detailed structure with all the signals requested in the encryption circuit is depicted in figure 6.

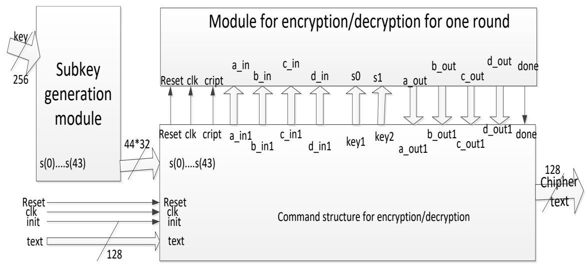


Fig. 6. Detailed structure for encryption circuit [11]

Table 1 shows the nodes and edges for RC6 [12].

Table. 1. Description of case study

Name	Nodes	Edges
RC6(RC6 cryptography graph)	329	448

6.2. Numerical experimentation

This paper presents MOIPO algorithm and compares its performance with the MOPSO algorithm. The performance of these evolutionary algorithms is evaluated by calculating the performance metrics namely Generational Distance (GD) and Spacing (S). The formula for calculating the Generational Distance (GD) is given in Equation (15) [6].

$$GD = \frac{(\sum_{i=1}^{M} d_i^2)^{1/2}}{M} \tag{15}$$

$$d_i = \min_{j=1}^{|T|} \sqrt{\sum_{n=1}^{N} (f_n^{(i)} - f_n^{(j)})^2} \tag{16}$$

M is the total number of solutions obtained; T the true pareto-optimal set; d_i is the Euclidean distance between the solution $i \in M$ and the nearest member of T ;

The formula for calculating the Spacing (S) is given in Equation (17) [6].

$$S = \sqrt{\frac{1}{M} \sum_{i=1}^{M} (d_i - \bar{d})^2} \tag{17}$$

$$\bar{d} = \sum_{i=1}^{M} \frac{d_i}{M} \tag{18}$$

Table 2 and 3 give the Parameters of the optimization algorithms used in this paper.

Table. 1. Parameters of MOIPO

Algorithm	Max it	K1	K2
MOIPO	100	5.09	$1.35*10^{-9}$

Scale1	Scale2	Shift1	Shift2
0.035	0.05	300	500

Table. 2. Parameters of MOPSO

Algorithm	Max it	C1	C2
MOPSO	100	3	3

The results for RC6 block cipher circuit using MOIPO and MOPSO algorithm are obtained. Table 4 displays the result of the proposed methods for GD and S.

Table. 3. Results of RC6 block cipher circuit using MOIPO and MOPSO algorithms

Algorithm	GD	S
MOIPO	13.62	176.61
MOPSO	27.56	258.6

The results demonstrate that MOIPO algorithm is more desirable than MOPSO algorithm, because MOIPO algorithm has much less Generational Distance (GD) and Spacing (S) in comparison to MOPSO algorithm.

Figures 7, and 8 show the pareto-optimal fronts obtained using the two algorithms MOIPO and MOPSO, respectively along with the VLSI circuit partitioning problem for RC6 block cipher.

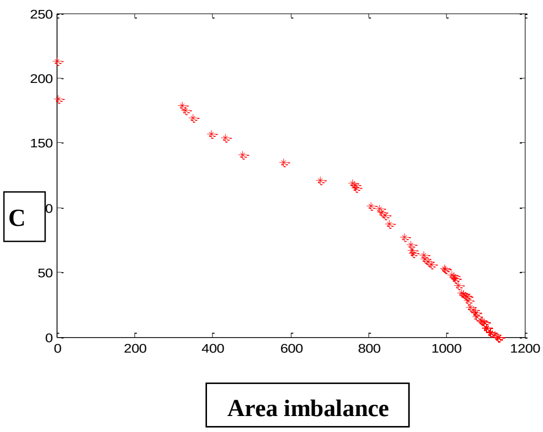


Fig. 7. Pareto-optimal front for MOIPO Area imbalance-vs-C

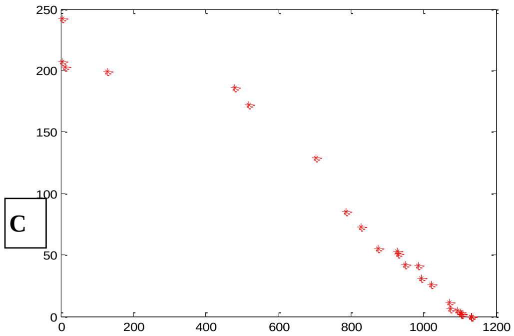


Fig. 8. Pareto-optimal front for MOPSO Area imbalance-vs-C

Figures 6, 7 show cost functions (cutsize and area imbalance) of RC6 block cipher circuit. Red stars in figures are repository members. Final answer has been chose between the repository members. the pareto-optimal fronts show that solutions Diversity in MOIPO algorithm more than MOPSO algorithm.

Figures 9, and 10 show the repository members in all 100 generation obtained using the two algorithms MOIPO and MOPSO, respectively.

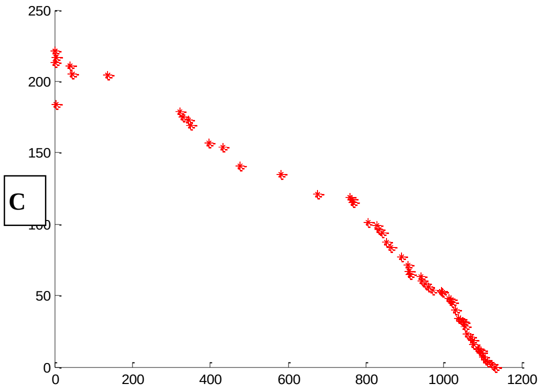


Fig. 9. Show the repository members in all 100 generation for MOIPO, Area imbalance-vs-C

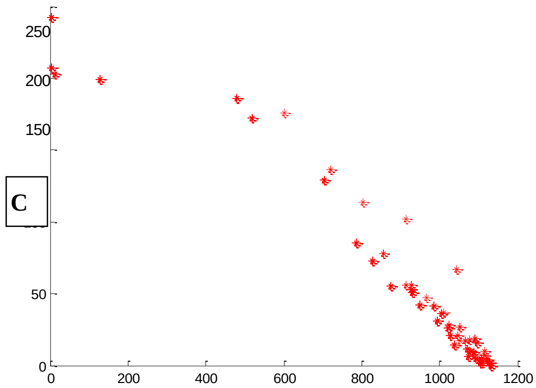


Fig. 10. Show the repository members in all 100 generation for MOPSO, Area imbalance-vs-C

7. Conclusion

Two evolutionary multi-objective optimization algorithms namely multi-objective inclined planes system optimization (MOIPO) algorithm, Multi-Objective Particle Swarm Optimization (MOPSO) presented for solving the VLSI circuit partitioning problem. The goal in this issue is to optimize two objectives namely area imbalanced and cutsize. The simulation results for RC6 block cipher circuit are examined and the pareto-optimal solutions obtained using these algorithms are compared to evaluate the efficiency of the algorithm. The performance of these evolutionary algorithms is evaluated by calculating the performance metrics namely Generational Distance (GD) and Spacing (S). The results demonstrate that MOIPO algorithm is more desirable than MOPSO algorithm, because MOIPO algorithm has much less Generational Distance (GD) and Spacing (S) in comparison to MOPSO algorithm.

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