Fuzzy Simulated Evolution for Power and Performance of VLSI Placement

Sadiq M. Sait Habib Youssef
Junaid A. Khan Aimane El-Maleh

Department of Computer Engineering
King Fahd University of Petroleum and Minerals
Dhahran, Saudi Arabia

Presentation Overview

- Introduction
- Problem statement and cost functions
- Proposed scheme
- Experiments and Results
- Conclusion

Introduction

- A Fuzzy Evolutionary Algorithm for VLSI placement is presented.
- Standard Cell Placement is:
  - A hard multi-objective combinatorial optimization problem.
  - With no known exact and efficient algorithm that can guarantee a solution of specific or desirable quality.
- Simulated Evolution is used to perform intelligent search towards better solution.
- Due to imprecise nature of design. information, objectives and constraints are expressed in fuzzy domain.
- New Fuzzy Operators are proposed.
- The proposed algorithm is compared with Genetic Algorithm.

Problem Statement & Cost Functions

Problem Statement

- Given
  - A set of modules M = {m_1,m_2,m_3,é m_n}
  - A set of signals V = {v_1, v_2, v_3,é v_k}
  - A set of Signals $V_i \subseteq V$, associated with each module $m_i \in M$
  - A set of modules M_j = {m_i|$v_j \in V_i$}, associated with each signal $v_j \in V$
  - A set of locations L = {L_1, L_2, L_3é L_p}, where $p \geq n$

- Objectives
  - The objective of the problem is to assign each $m_i \in M$ a unique location L_j, such that
  - Power is optimized
  - Delay is optimized
  - Wire length is optimized
  - Within accepted layout Width (Constraint)

Cost Functions

- Wire length Estimation

$$Cost_{wire} = \sum_{i \in M} l_i$$

Where

l_i …… is the estimate of actual length of signal net v_i, computed using median Steiner tree technique

- Power Estimation

$$P_t \approx \sum_{i \in M} \frac{1}{2} C_i \cdot V^2{}_{DD} \cdot f \cdot S_i \cdot \beta$$

Where:

S_i …… Switching probability of module m_i

C_i …… Load Capacitance of module m_i

V_{DD} … Supply Voltage

f …… Operating frequency

β …… Technology dependent constant

Cost Functions

- Power Estimation (contd.)
  - Also

$$C_i = C_i^r + \sum_{j \in M_i} C_j^g$$

Where

C_i^r é é Interconnect capacitance at the output node of cell i.
C_j^g é é Input capacitance of cell j.

- In standard cell placement V_{DD}, f, β, and C_j^g are constant and power dissipation depends only on S_i and C_i^r which is proportional to wire-length of the net v_i. Therefore the cost due to power can be written as:

$$Cost_{power} = \sum_{i \in M} S_i \cdot l_i$$

Cost Functions

- Delay Estimation
  - We have a set of critical paths $\{\pi_1, \pi_2, \pi_3$é é $\pi_k\}$
  - $\{v_{i1}, v_{i2}, v_{i3}$é é $v_{iq}\}$ is the set of signal nets traversing path $\pi_{i.}$
  - $T_{\pi i}$ is the delay of path π_i computed as:

$$T_{\pi i} = \sum_{i=1}^{q} (CD_i + ID_i)$$

Where

CD_i ...... is the delay due to the cell driving signal net v_i.

ID_i ...... is the interconnect delay of signal net v_i.

Now

$$Cost_{delay} = \max(T_{\pi i}) \ldots . \forall i \in \{1,2,3,4 \ldots \ldots k\}$$

Cost Functions

- Width Constraint

$$Width_{\max} = (1 + a) \times Width_{opt}$$

Where

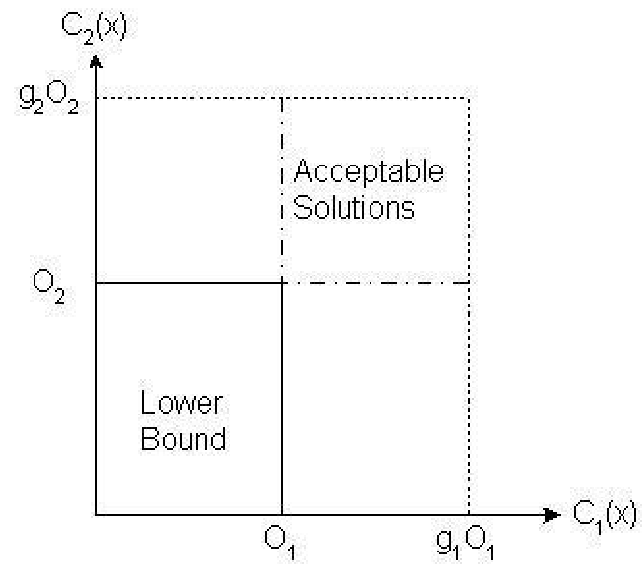
$\mathrm{Width}_{\mathrm{max}}$ … is the max. allowable width of layout

$\mathrm{Width}_{\mathrm{opt}}$ … is the optimal width of layout

a …… denotes how wide layout we can have as compared to its optimal value.

Fuzzy Cost Measure

- Set of solutions is generated by SE.
- Best solution is one, which performs better in terms of all objectives and satisfies the constraint.
- Due to multi-objective nature of this NP hard problem fuzzy logic (fuzzy goal based computation) is employed in modeling the single aggregating function.



Range of acceptable solution set

Fuzzy Cost Measure

- Fuzzy Operators used
  - And-like operators
    - Min operator

      $\mu = \min(\mu_1, \mu_2)$
    - And-like OWA

      $\mu = \beta \text{ x } \min(\mu_1, \mu_2) + ½ (1-\beta)(\mu_1 + \mu_2)$
    - Fuzzy Controlled And Operator (FCAO)

      $\mu = 1- (\mu_1^{/\,2} + \mu_2^{/2})/(\mu_1^{/} + \mu_2^{/})$
  - Or-like operators
    - Max operator

      $\mu = \max(\mu_1, \mu_2)$
    - Or-like OWA

      $\mu = \beta \text{ x } \max(\mu_1, \mu_2) + ½ (1- \beta)(\mu_1 + \mu_2)$
    - Fuzzy Controlled OR Operator (FCOO)

      $\mu = (\mu_1^{\,2} + \mu_2^{2})/(\mu_1 + \mu_2)$

Fuzzy Cost Measure

- Following fuzzy rule is suggested in order to combine all objectives and constraint

$$\mu^{c}{}_{pdl}(x) = 1 - \frac{\mu'^{c2}_{p} + \mu'^{c2}_{d} + \mu'^{c2}_{l}}{\mu'^{c}_{p} + \mu'^{c}_{d} + \mu'^{c}_{l}}$$

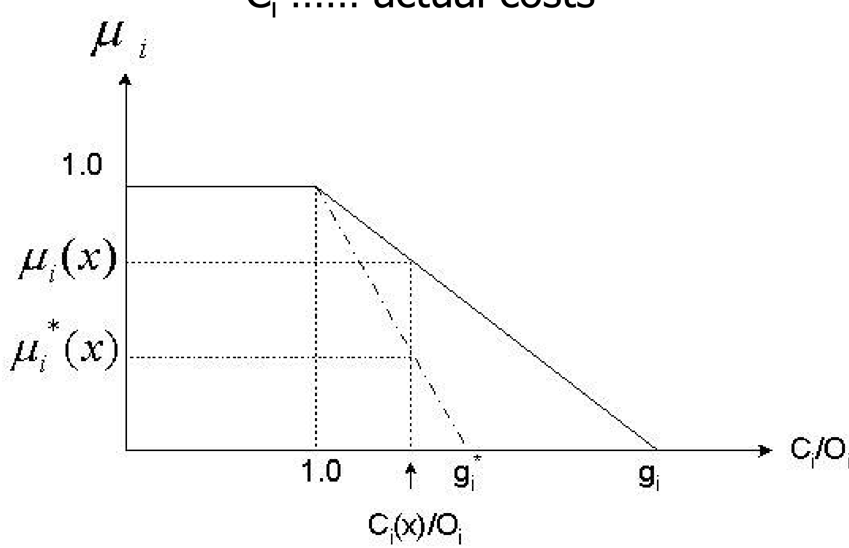
IF a solution is within acceptable wire-length AND acceptable power AND acceptable delay AND within acceptable layout width

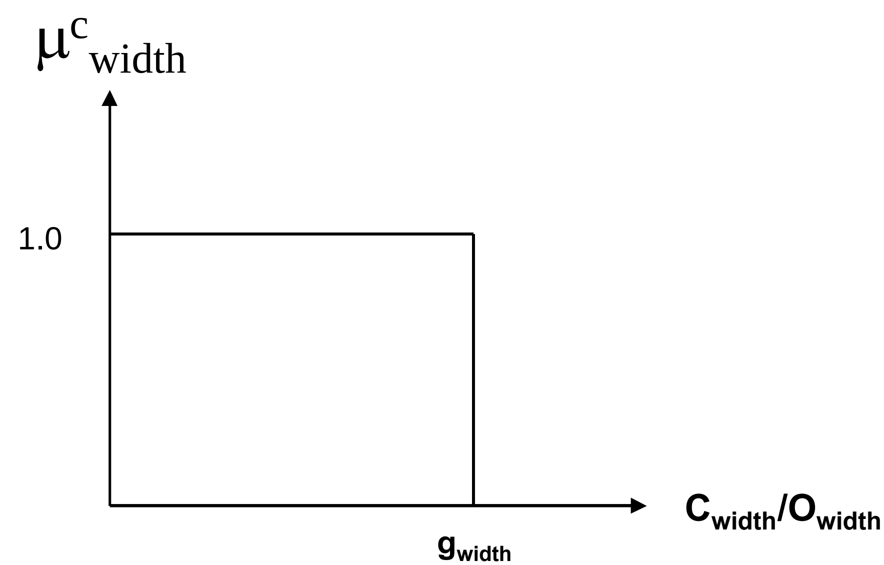
THEN it is an acceptable solution

$$\mu^{c}(x) = \min(\mu^{c}{}_{pdl}(x), \mu^{c}{}_{width}(x))$$

Fuzzy Cost Measure

O_i …… optimal costs
C_i …… actual costs





Shape of membership functions

Proposed Scheme

SE Algorithm

ALGORITHM SimE(M,L)
/* M: Set of moveable elements */
/* L: Set of locations */
/* B: Selection bias */
INITIALIZAION:
Repeat
    EVALUATION:
        For Each m $\in$ M
            compute(g_m)
        End For Each
    SELECTION:
        For Each m $\in$ M
            If Selection(m,B) **Then**
                $P_s = P_s \cup \{m\}$
            Else $P_r = P_r \cup \{m\}$
            End If
        End For Each
    Sort the elements of P_s;
    ALLOCATION:
        For Each m $\in$ P_s
            Allocation(m)
        End For Each
Until Stopping criteria are met
Return (Best Solution)
End SimE

Proposed Fuzzy goodness evaluation

IF cell i is

near its optimal wire-length AND near its optimal power AND near its optimal net delay OR T_{max}(i) is much smaller than T_{max} **THEN** it has high goodness.

$$\mu_i^e(x) = \beta^e \times \min(\mu_{iw}^e(x), \mu_{ip}^e(x), \mu i_d^e(x))$$
$$+(1-\beta^e)\frac{1}{3}\sum_{j=w,p,d}\mu_{ij}^e(x)$$

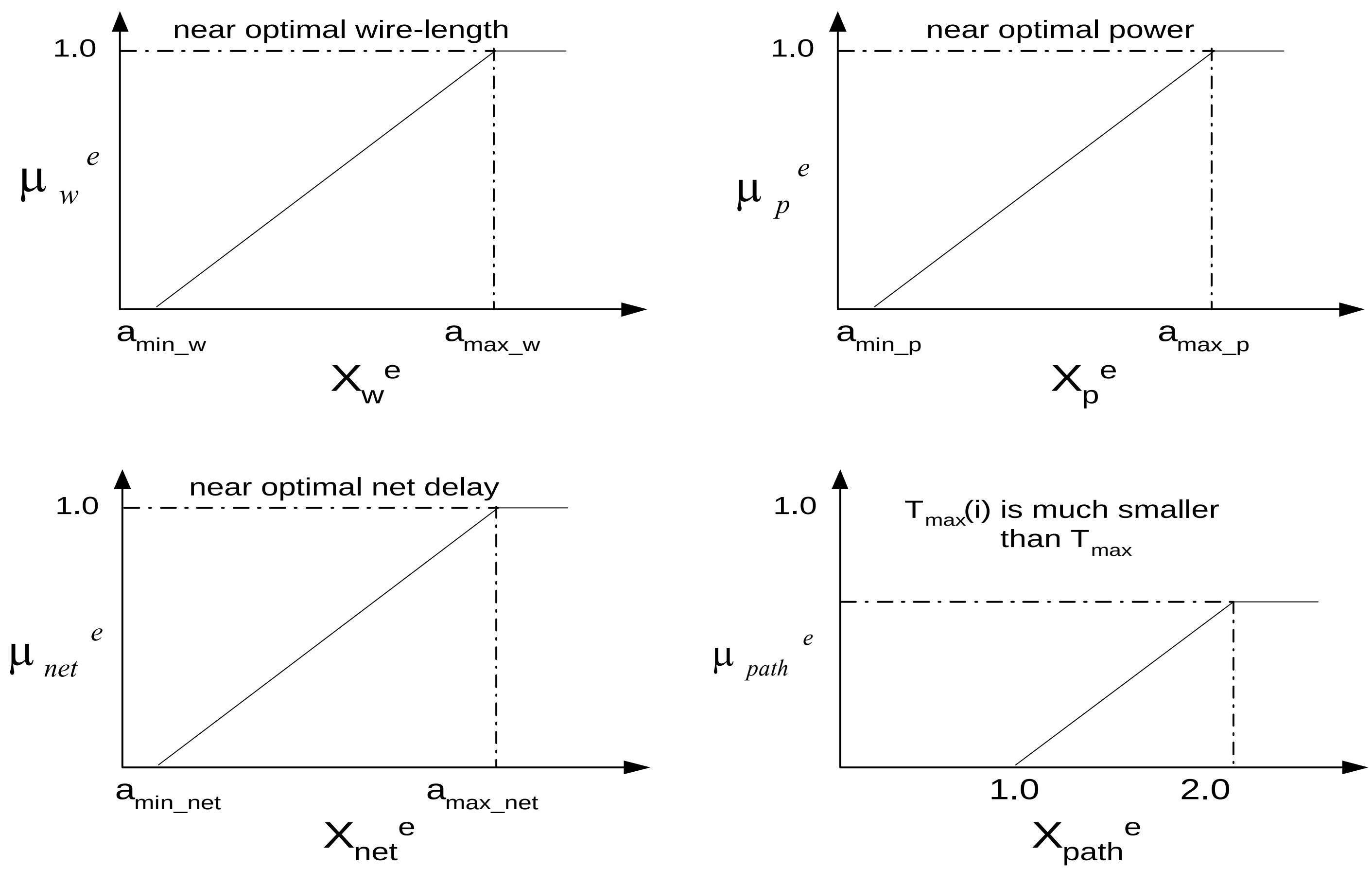
Where

Where

T_{max} is the delay of the most critical path in the current iteration and T_{max}(i) is the delay of the longest path traversing cell i in the current iteration

$$\mu_{id}^e(x) = \beta_d^e \times \max(\mu^e_{inet}(x), \mu^e_{ipath}(x)) +$$
$$(1-\beta_d^e)\frac{1}{2}(\mu^e_{inet}(x) + \mu^e_{ipath}(x))$$

Goodness (Membership Functions)



Goodness (base values)

$$X_{iw}^{\ e}(x) = \frac{\sum_{j=1}^{k} l^{*}_{j}}{\sum_{j=1}^{k} l_{j}}$$

$$X_{ip}^{\ e}(x) = \frac{\sum_{j=1}^{k} S_{j}.l^{*}_{j}}{\sum_{j=1}^{Ki} S_{j}.l_{j}}$$

$$X^{e}_{inet}(x) = \frac{ID_i^{\ *} + ID_p^{\ *}}{ID_i + ID_p}$$

$$X^{e}_{ipath}(x) = \frac{T_{\max}}{T_{\max}(i)}$$

Where

- l^{*}_{j} ...... lower bound on wire length of signal net v_j
- l_j ...... actual wire length of signal net v_j
- S_j ...... is the switching probability of v_i

Where

- ID_i^{*} ...... is the lower bound on interconnect delay of v_i
- ID_p^{*} ...... is the lower bound on interconnect delay of the input net of cell i that is on $\pi_{max}(i)$
- $T_{max}(i)$ ...... Delay of longest path traversing cell i
- T_{max} ...... Delay of most critical path in current iteration

- Goodness (a_{min_i} and a_{max_i})

a_{min_i} = average(X^e_i) ï 2xSD(X^e_i)

a_{max_i} = average(X^e_i) + 2xSD(X^e_i)

- Selection

A cell i will be selected if

$$\text{Rndom} \geq g_i + \text{bias}$$

Range of the random number will be fixed , i.e., [0,M]

$$M = \text{average}(g_i) + 2 \text{ x } SD(g_i)$$

M is computed in first few iteration, and updated only once when size of selection set is 90% of its initial size

Allocation

- Selected cells are sorted w.r.t. their connectivity to non-selected cells.
- Top of the list cell is picked and swapped its location with other cells in the selection set or with dummy cells, the best swap is accepted and cell is removed from the selection set.
- Following Fuzzy Rule is used to find good swap

IF a swap results in

reduced overall wire length AND
reduced overall power AND
reduced overall delay AND within acceptable layout width

THEN it gives good location

Allocation (contd.)

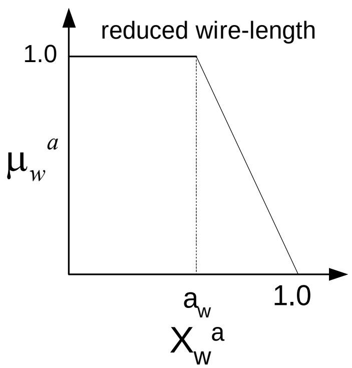
$$\mu^{a}{}_{i\_pwd}(l) = \beta^{a} \min(\mu^{a}{}_{iw}(l), \mu^{a}{}_{ip}(l), \mu^{a}{}_{id}(l)) + (1-\beta^{a})\frac{1}{3}\sum_{j=p,w,d}\mu^{a}{}_{ij}(l)$$

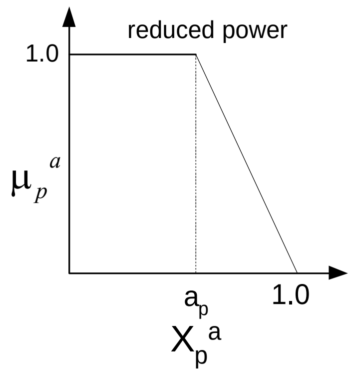
$$\mu_{i}{}^{a}(l) = \min(\mu^{a}{}_{i\_width}(l), \mu^{a}{}_{i\_pwd}(l))$$

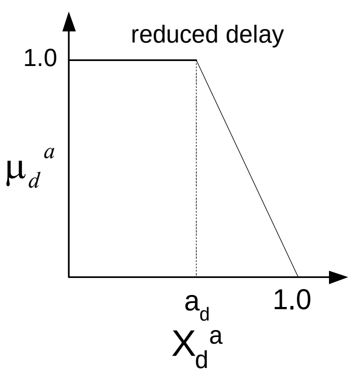
Where

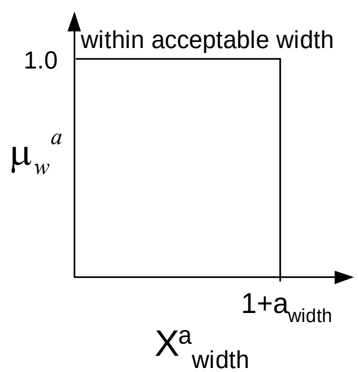
- l …… represents a location
- $\mu_{iw}{}^{a}$ …… membership in fuzzy set, reduced wire length
- $\mu_{ip}{}^{a}$ …… membership in fuzzy set, reduced power
- $\mu_{id}{}^{a}$ …… membership in fuzzy set, reduced delay
- $\mu^{a}{}_{i\_width}$ …… membership in fuzzy set, smaller layout width
- $\mu_{i}{}^{a}(l)$ …… is the membership in fuzzy set of good location for cell i

...on (Membership functions)









$$X^a{}_{iw}(l) = \frac{(\sum_{m=1}^{ki} l_{im} + \sum_{m=1}^{kj} l_{jm})_n}{(\sum_{m=1}^{ki} l_{im} + \sum_{m=1}^{kj} l_{jm})_{n-1}}$$

$$X^a{}_{ip}(l) = \frac{(\sum_{m=1}^{ki} S_{im} l_{im} + \sum_{m=1}^{kj} S_{jm} l_{jm})_n}{(\sum_{m=1}^{ki} S_{im} l_{im} + \sum_{m=1}^{kj} S_{jm} l_{jm})_{n-1}}$$

$$X^a{}_{id}(l) = \frac{(ID_i + ID_{ip} + ID_j + ID_{jp})_n}{(ID_i + ID_{ip} + ID_j + ID_{jp})_{n-1}}$$

$$X^a{}_{i\_width(l)} = \frac{Cost_{Width_n}}{Width_{opt}}$$

These values are computed when cell i swap its location with cell j, in n^{th} iteration

Genetic Algorithm

- Membership value $\mu^c(x)$ is used as the fitness value.
- Roulette wheel selection scheme is used for parent selection.
- Partially Mapped Crossover is used.
- Extended Elitism Random Selection is used for the creation of next generation.
- Variable mutation rate in the range [0.03-0.05] is used depending upon the standard deviation of the fitness value in a population.

Experiments and Results

Technology Details

- .25 μ MOSIS TSMC CMOS technology library is used
- Metal1 is used for the routing in horizontal tracks
- Metal2 is used for the routing in vertical tracks

Metal Type	ω (μm)	R_{sh} $\Omega/\square$	C_p aF/μ^2	C_f aF/μ
Metal 1	0.36	0.07	39	26
Metal 2	0.36	0.07	19	60

0.25 μ technology parameters

Circuits and Layout Details

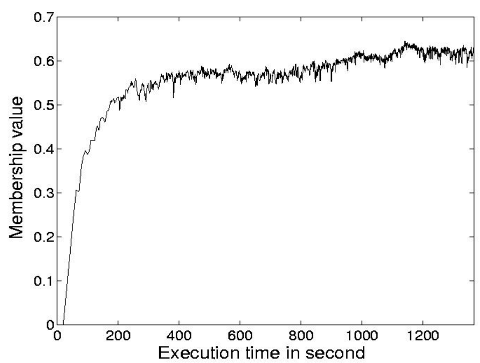
Circuit		Layout	
Name	Number of Cells	Number of Rows	Average Channel Height in μm
S2081	122	4	6.66
S298	136	5	7.08
S386	172	5	7.68
S641	433	7	9.72
S832	310	7	9.78
S953	440	8	11.76
S1196	561	9	11.58
S1238	540	9	11.64
S1488	667	11	10.92
S1494	661	11	10.56
C3540	1753	16	13.68

Results

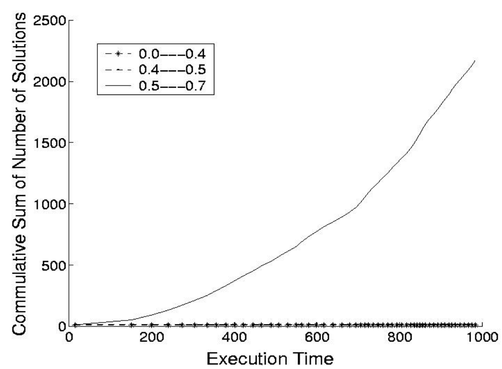
Table 1: Layout found by FSE with CFO, FSE with OWA and GA. "L", "P" and "D" represent the wire-length, power, and delay costs and "T" represents execution time in seconds.

Circuit	FSE with CFO				FSE with OWA				GA			
	L (μm)	P (μm)	D (ps)	T (s)	L (μm)	P (μm)	D (ps)	T(s)	L (μm)	P (μm)	D (ps)	T (s)
S2081	2639	431	114	92	2693	462	112	43	2426	388	113	2341
S298	5130	946	142	84	4989	1013	133	104	4062	838	130	2922
S386	7097	1707	196	314	7088	1640	197	152	6824	1665	181	3945
S832	23959	5253	399	365	24705	5827	390	1643	21015	4787	232	7206
S641	11499	2691	689	680	13906	3321	702	618	18320	4365	736	21982
S953	31846	4883	237	942	32340	5242	245	1278	32031	5156	230	11221
S1238	40726	12696	383	585	39629	12377	371	1168	52679	15473	410	16208
S1196	38041	11606	351	999	42426	12745	364	1521	51804	15259	370	23070
S1494	55010	13628	699	2979	56961	14071	719	3378	71021	17497	803	26032
S1488	56875	13835	706	5357	57091	13887	710	3529	69792	17346	784	21434
C3540	164156	58002	686	10013	164897	58055	734	18318	310996	109850	924	43232

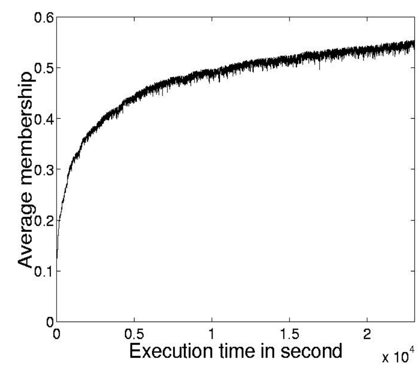
Results



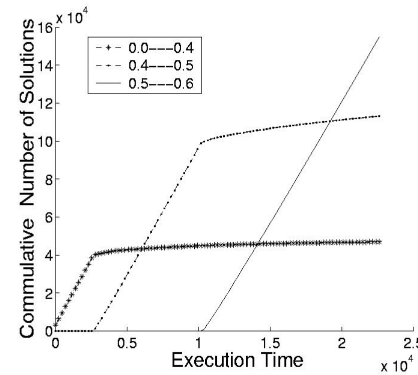
(a)



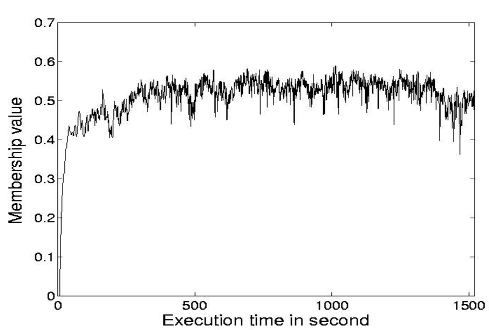
(d)



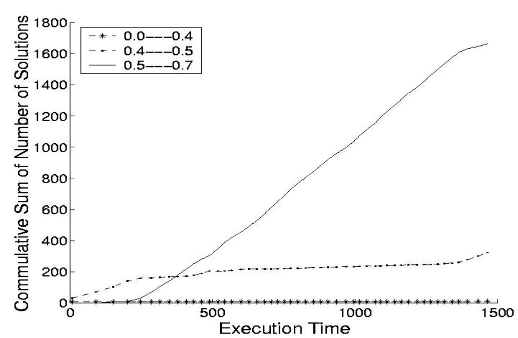
(c)



(f)



(b)



(e)

(a), (b), and (c) show membership value vs. execution time for FSE with CFO, FSE with OWA and GA. (d), (e), and (f) show cumulative number of solutions visited in specific membership ranges vs. execution time for FSE with CFO, FSE with OWA and GA respectively

Conclusion

- Fuzzy Simulated Evolution Algorithm for VLSI standard cell placement is presented.
- Fuzzy logic is used in Evaluation, and allocation stages of the SE algorithm and in the selection of best solution.
- New Controlled Fuzzy Operators are presented.
- The proposed scheme is compared with GA and with OWA operators.
- FSE performs better than GA with less execution time and better quality of final solution.
- FSE has better evolutionary rate as compared to GA.
- CFO gives solution with same or better quality without the need of any parameter like β.
- CFO exhibits better evolutionary rate than OWA.