A Fuzzified Router for Multi-objective Global Routing in VLSI Physical Design

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Abstract: Many approaches have been used towards global routing in VLSI physical design including sequential, concurrent and meta-heuristic approaches making use of optimization algorithms like Artificial Bee Colony algorithm (ABC), Ant Colony optimization (ACO), Particle Swarm Optimization (PSO), Discrete PSO and its variants. In this paper a fuzzified global router is presented to overcome the limitations of deterministic approaches.

Keywords: Global Routing, FLC, GUI, Sensitivity, Congestion, Manhattan distance.

Introduction

Routing is an important stage in VLSI Physical design in the designing of integrated circuits (ICs). It generates wiring to interconnect pins of the same signal, while obeying the manufacturing design rules. The goal of a router is to complete the circuit connections using shortest possible wire length [1]. Routing is typically a very complex combinatorial problem. To make it manageable, the routing problem is usually solved by the use of a two-stage approach of a) Global routing b) Detailed routing. The recent researches on global routing are aimed to optimize different multi objective functions related to performanceand congestion driven routing, thermal aware routing, sensitivity aware routing,minimization of wire length and number of critical paths, obstacle aware routing problem in recent era′s OTC routing using various optimization algorithms like ACO [3], ABC [4], PSO [2], DPSO [5] along with its variants and the latest Discrete Differential Evolution [6]. But there is very less initiation of fuzzified approach for global routing which can remove problems of deterministic approaches. Fuzzy logic deals with reasoning that is approximate rather than fixed and exact and moreover in contrast with traditional logic, binary sets in fuzzy have two-valued logic, true or false, whose variable value ranges in degree between 0 and 1. A fuzzy set introduces vagueness by banishing the sharp boundary that segregates members from non-members in the group [7]. The basic idea behind Fuzzy Logic Control (FLC) is to assimilate the expertiseof a human operator in design of controller in controlling a process whose input output relationship is outlined by a collection of fuzzy control rules (e.g. IF-THEN rules) involving linguistic variables rather than a complex dynamic model.

Problem formulation

Problem statement

Let K= k_1, k_2, k_3..., $k_m$be a set of pins of 'm' pin net distributed across the routing layer. Let P = p_1, p_2, p_3 ..., p_k be a set of 'k' modules spread over the routing layer, where, each p_i has its bottom left coordinates (x_i, y_i). The sensitivity, congestion and distance factor for each module will determined according to the algorithm. The three cost factor parameters namely α, β, and γ will also be provided, where $\alpha+\beta+\gamma$ =1. The weighted cost factor will be generated from the sensitivity, congestion and distance factor information incorporated with the α, β, and γ values [7].

Problem description

The entire routing layer is represented as a grid structure whose size is user defined. The modules are drawn by multiple grids over x and y direction in the routing layer. Each grid has its own sensitivity value which corresponds to the temperature. If the sum of the sensitivity of the grids of an area is very high, region becomes a hotspot as heat dissipation of that area is very large. So avoiding those hot spots during routing is a major challenge. Thus the preferable routing region from a source will be one having low sensitivity, least congested and also at least distance to the target. So with the increasing number of pre-routed nets traffic of nets increases hence, routing in a netlist becomes critical for the latter nets [7]. The routing eligibility is inversely proportional to the thermal sensitivity, congestion and distance factor of each subregion. That is why ineligibility factor has been considered the linguistic variable in consequent part.

Fuzzification of sensitivity, congestion and distance factor

In premise part of designed fuzzy router, thermal sensitivity, congestion ratio and distance all are the input linguistic variables varying between [0,1]. The derived nine fuzzy sets from the three linguistic variables are shown in Table 1.

Table 1. Derived Fuzzy Sets from Linguistic Variables

Sensitivity	Least sensitive (LS) Medium sensitive (MS) Highly sensitive (HS)
Congestion	Least Congested (LC) Medium Congested (MC) Highly Congested (HC)
Distance Factor	Maximum Distance (MD) Intermediate Distance (ID) Least Distance (LD)

Fuzzification of ineligibility factor

In the consequent part ineligibility factor is the linguistic variable. For original rule base there are total 27 fuzzy sets. The ineligibility weight factor (μ_r) depends upon sensitivity ratio (s_r), congestion ratio (o_r), and distance factor (p_r) and is calculated as shown in eq. (1):

$$\mu_r = f(\alpha, s_r, \beta, o_r, \gamma, p_r) = \frac{(\alpha \times s_r + \beta \times o_r + \gamma \times p_r)}{(\alpha+\beta+\gamma)} \quad (1)$$

where the three cost factor coefficients viz. α, β, and γ are used to specify the relative weights of Sensitivity, congestion and distance factor [8] and $\alpha+\beta+\gamma=1$.

Methodology

In this work, a fuzzified global router is designed to achieve multi-objective routing with the main focus on finding the routing path as per the user requirement depending upon his/her priority for Congestion, Sensitivity or Distance. The guiding information and expert system is generated as prior information before actual routing as shown in Fig.1. After generation of rule base a fuzzy expert system is constructed. Then a sequence of dedicated sub regions for global routing between source and destination is generated. The Algorithm iterates over Manhattan distance between source and destination sub region continuously updating the source sub region and stops when the distance become zero.

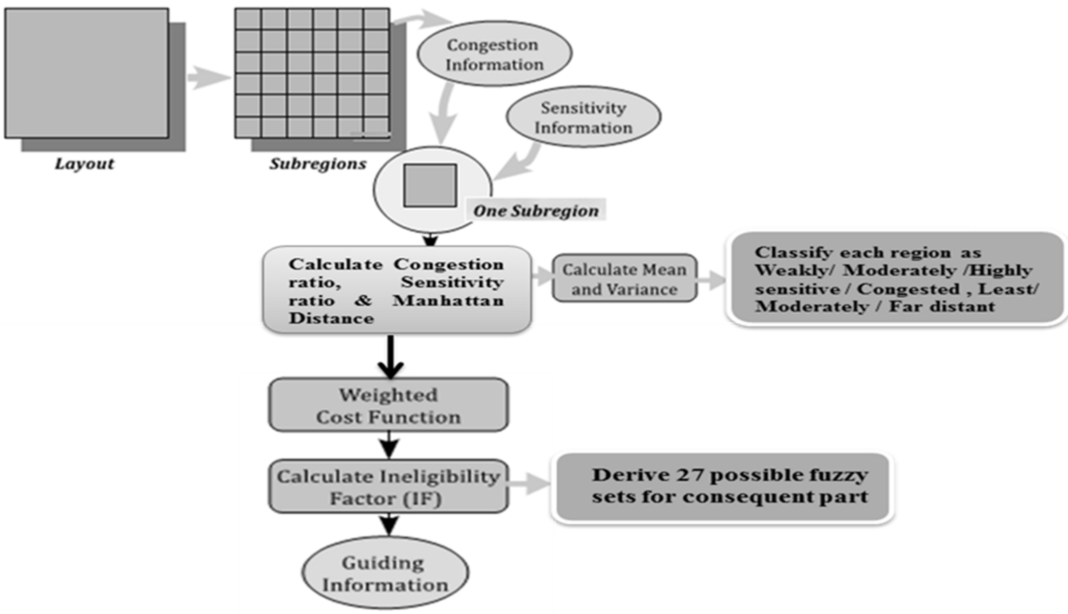

Figure 1. Block representation of guiding information generation for global routing

Starting from the source sub region the guiding information for its four neighbour are passed to fuzzy expert system which determine the ineligibility factors for each neighbour with help of the designed expert system. A scenario of source to target intra-layer global routing is shown in Fig. 2.

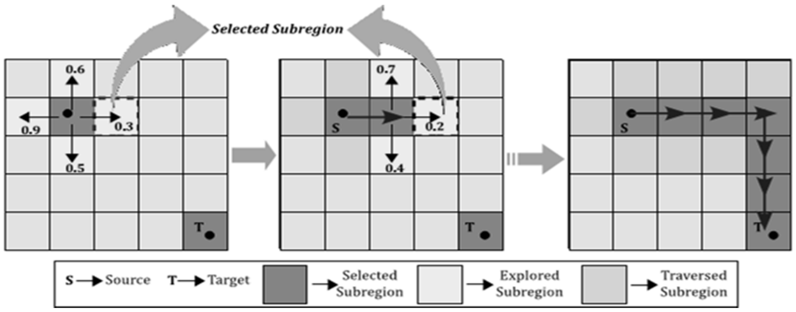

Figure 2. A scenario of source to target intra-layer global routing

Results and discussion

The performance of the designed fuzzified global router for multi-objective routing is tested on GUI which has been created using guide command in MATLAB. Input parameters α (for thermal sensitivity), β (for congestion ratio), γ (for distance factor) are given as input set [0.66 0.55 0.33] to the fuzzy system developed and output i.e. ineligibility factor has been determined based on the rule base described earlier and is obtained as μ_r = 0.55 as shown in Fig. 3.

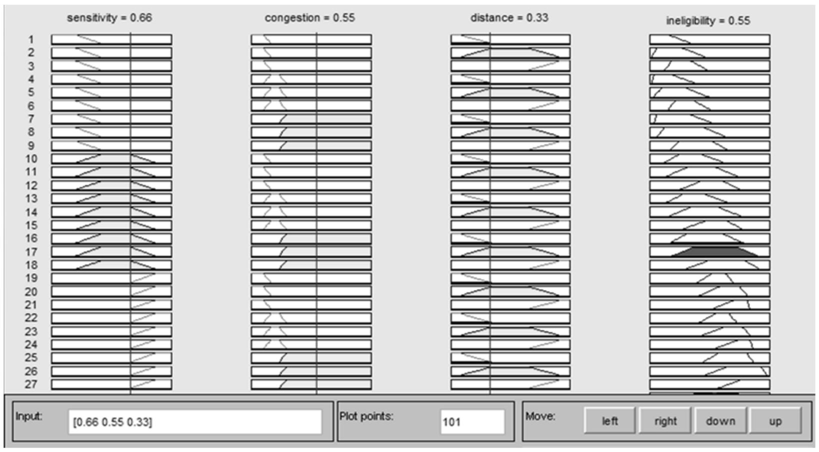

Figure 3. Ineligibility factor calculations using fuzzy expert system designed using fuzzy toolbox in MATLAB

Test case 1

The parameters used for test case I are mentioned in Table 2 and the resulting global routing paths are shown in Fig. 4.

Table 2. Parameters of Test case I

Parameters	Values
Width and Height of layout	[3 3]
Number of modules	10
Sensitivity of each module	[0.42 0.09 0.25 0.17 0.8 0.95 0.87 0.75 0.72 0.6]
Dimensions (bottom left corner) for the modules: (x-y-width-height)	0.3 2.3 0.4 0.4; 1.4 2.4 0.4 0.4; 0.8 1.6 0.5 0.6; 1.7 1.7 0.5 0.4; 2.4 1.8 0.4 0.5; 0.2 1.2 0.4 0.4; 1.5 0 0.4 0.4; 0.2 0.3 0.6 0.4; 1.2 0.6 0.4 0.3; 1.9 0.6 0.4 0.3
Source coordinate	[0.5 2.7]
Destination Coordinate	[1.5 0.6]

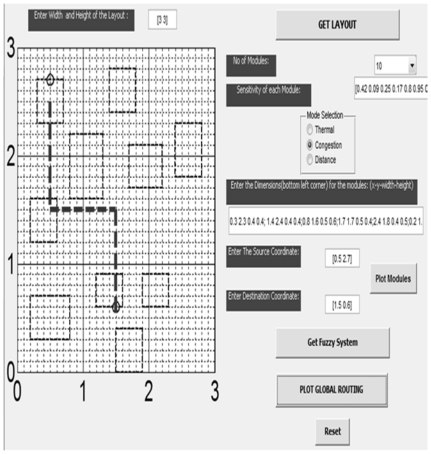

Figure 4. Global routing path connecting source and target pin for Test case I in (a) Thermal mode (b) Congestion mode (c) Distance model

Test case 2

The parameters used for test case II are mentioned in Table 3 and the resulting global routing paths are shown in Fig. 5.

Table 3. Parameters of Test case II

Parameters	Values
Width and Height of layout	[3 3]
Number of modules	10
Sensitivity of each module	[0.42 0.29 0.45 0.37 0.8 0.95 0.87 0.75 0.72 0.8]
Dimensions (bottom left corner) for the modules: (x-y-width-height)	0.3 2.3 0.4 0.4; 2.4 0.4 0.4 0.4; 0.8 1.6 0.5 0.6; 1.7 1.7 0.5 0.4; 2.6 2.0 0.3 0.5; 0.2 1.2 0.4 0.4; 1.5 0 0.4 0.4; 0.2 0.3 0.6 0.4; 1.2 0.6 0.4 0.3; 2.1 1.2 0.4 0.3
Source coordinate	[0.5 2.7]
Destination Coordinate	[2.5 1.5]

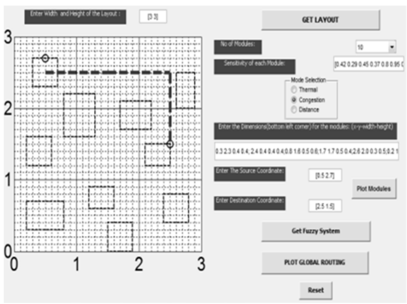

Figure 5. Global routing path connecting source and target pin for Test case II in (a) Thermal mode (b) Congestion mode (c) Distance mode

Conclusion

In this paper, fuzzy approach has been successfully used to perform multi-objective routing to minimize the weighted cost function i.e. ineligibility factor maintaining three constraints viz. thermal sensitivity, congestion ratio and manhattan distance for each net. Moreover, the objective of finding the routing path as per the user requirement i.e. depending upon his/her priority for Congestion, Sensitivity or Distance has been successfully carried out with the help of implemented fuzzy expert system and verified by taking two test cases on the GUI created in MATLAB. Thus, fuzzy approach may also be considered as a new type of guided global routing approach. Moreover in fuzzified approach the search space is decreased for a particular solution, so the time and design complexity thereby overcoming the limitations of deterministic approaches. This work only explores the feasibility study & I have not implemented it for any benchmark. Thus different types of comparative analysis, applications in Steiner tree, implementation for any ISPD / IBM benchmarks, obstacle avoidance and enhancement to 3D ICs may be considered as some possible extensions of the present work.

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