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Research on channel routing model of integrated circuit

Teng Zhang

School of Electrical and Information Engineering, Anhui University of Science and Technology, Huainan, Anhui, 232001, China

Abstract: *Based on the research and analysis of integrated circuit routing problem, this paper puts forward a judgment method of no solution for one layer metal channel routing, establishes an optimal routing model for one layer metal routing problem based on 0-1 integer linear programming, an optimal routing algorithm for multi-layer metal routing problem with via, and an improved model for multi-layer metal routing problem with via spacing.*

Keywords: *0-1 integer linear programming, optimal path, lingo*

1. Introduction

Integrated circuit design is composed of several stages, one of which is called "physical design". Firstly, the devices are placed in the right position, and then the metal wires are used to connect the devices to realize the connection relationship. In short, assuming that the available area is composed of $n \times m$ squares, the metal wires are allowed to be placed along a straight line or right angle (square), and the specified squares (pins) are connected without causing open circuit or short circuit, this process is called "wiring". Because the parasitic resistance introduced by the metal wire will affect the circuit performance, it is necessary to minimize the wiring length. This paper will solve the following problems.

(1) Suppose a layer of metal wiring is used, then the grid that has been wired is locked and other lines are not allowed to pass through, otherwise a short circuit will be formed. Please complete the modeling and solution for the "channel routing" problem of this layer of metal, and answer the following question: under what circumstances, there is no solution for the "channel routing" problem of this layer of metal.

(2) It can be observed that some test cases can not use a layer of metal to complete the wiring. In practice, integrated circuits will use multiple metal layers, different metal layers at different heights, adjacent layers need to be connected by through holes, so that different metal layers can share a grid without short circuit. Assuming that the resistance of a through hole is equal to a wire with 5 squares, please use up to 3 layers of metal to re model and solve the "channel routing".

(3) With the reduction of IC size, the new through hole manufacturing process requires that the distance between any two through holes must be greater than or equal to two grid points. Please add the constraints related to the through holes and solve the problem again.

2. Model Establishment and Solution

2.1 Problem 1

2.1.1 Linear Programming Model

The "channel routing" problem of one layer metal is a large-scale linear programming (LP) problem. In the final analysis, the problem is an optimal tree problem, which finds three optimal paths without short circuit. There are two algorithms to solve the optimal tree in graph theory: Kruskal algorithm (or cycle avoiding method) and prim algorithm (cycle breaking method) [1]

First, judge whether the given two kinds of data have solutions. Suppose that the i-th number of "upper pin coordinates" and "lower pin coordinates" are a_i and b_i respectively, which means that the a_i grid point of the first row needs to be connected with the b_i grid point of the nth row. If the lower pin coordinate is changed to the upper pin coordinate, if the two sequences are consistent, there will be no short circuit. The data of the two situations are shown in Figure 1 and Figure 2 respectively.

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	3		5	6	
1(3)		4(5)			7(6)

Figure 1

1				5	6	8			12
	2(6)	3(1)	4(8)				9(12)	10(5)	

Figure 2

It can be seen from the figure that the order of pins in Figure 2 is 6-1-8-12-5, which is different from 1-5-6-8-12, so the data in Figure 1 has a solution, but that in Figure 2 has no solution.

Firstly, we number the 4 * 7 table, and specify that the distance of each grid is 1. The number is shown in Table 1.

Table 1

1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Then we give a method to solve the graph one optimal tree by lingo. We establish a 0-1 integer linear programming (BIP) model,

$$x_{ij} = \begin{cases} 1; \text{ Node i is connected to node j;} \\ 0; \text{ Node i is not connected to node j;} \end{cases}$$

Suppose that an undirected graph has a total of n nodes, and the adjacency matrix of its weighted graph is $d_{m\times n}$. d_{ij} represents the distance from the node to the node. d is a symmetric matrix. $d_{ii}=0$.

The optimal tree from root node 1 to each node is obtained, and the sum of weights on each line is required to be minimum. The linear programming model is as follows:

(1) Decision variables: $x_{ij} = \begin{cases} 1; \text{ Node i is connected to node j;} \\ 0; \text{ Node i is not connected to node j;} \end{cases}$

(2) The objective function is to find the optimal tree from 3,5,6 to 1,4,7, which requires the minimum weight on each path. So the objective function is $\min z=\sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}x_{ij}$

(3) There is at least one way out for starting points 3, 5 and 6. $\sum_{j=1}^{n} X_{pj} \geq 1$, p=3,5,6

(4) For the rest of the points, there is at most one way to enter. $\max\{x_{kj}=1\}$, j=1…28, k=1,i≠k

The total linear programming model is as follows:

$$\min z=\sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}x_{ij}$$

$$s.t.\begin{cases} \sum_{j=1}^{n} X_{pj} \geq 1 \\ \text{Max}\{x_{kj}=1\}, \ j=1\ldots 28, \ k=1, i\neq k \\ x_{ij}=0或1 \end{cases}$$

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2.1.2 Model Solution

The 0-1 integer programming problem is solved in lingo. The results are shown in Table 2, and the optimal channel routing is shown in Figure 3.

Table 2

X(3,2)=1	X(5,4)=1	X(6,7)=1
X(2,1)=1	X(4,11)=1	X(7,14)=1
X=(1,8)=1	X(11,18)=1	X(14,21)=1
X(8,15)=1	X(18,25)=1	X(21,28)=1
X(15,22)=1		

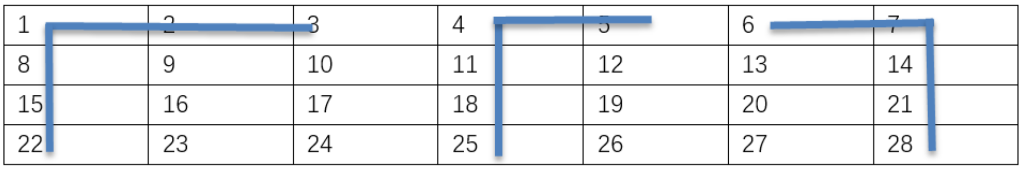

Figure 3

2.1.3 The case of routing problem without solution

Target Function: $\min z = \sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij} x_{ij}$

There is at least one way out for starting points 3, 5, 6, $\sum_{j=1}^{n} X_{pj} \geq 1$, p=3,5,6

For other points, there is at most one way to enter: $\max\{x_{kj} > 1\}$, j=1…28, k=1,i≠k

It can be seen that the model has no solution when there is more than one line in each point, that is, short circuit.

2.2 Problem 2

This paper is a three-layer metal channel routing problem. Compared with the one-layer metal routing problem in problem 1, the computational complexity increases exponentially with the increase of the number of pins and the routing area. Firstly, we establish a 0-1 integer linear programming model (BIP) to minimize the weight of each path. All the cases on one layer of metal are calculated, and the data of two times of short circuit is obtained through continuous screening, so that the problem of short circuit can be solved by using three layers of metal [2].

In the 0-1 integer linear programming (BIP) model,

$$y_{ij} = \begin{cases} 1; \text{ Node i is connected to node j;} \\ 0; \text{ Node i is not connected to node j;} \end{cases}$$

Target Function: $\min G = \sum_{b=1}^{m}\sum_{b=1}^{m} H_{ab} Y_{ab}$; a=b=1…72

There is at least one way out of the starting point, $\sum_{b=1}^{m} Y_{qb} \geq 1$, q=1,5,6,8,12

For the remaining points, there are at most two paths to enter: $\max\{x_{kb} = 2\}$; b=1…72, k=1, a≠k

The total linear programming model is as follows:

$$\min G = \sum_{b=1}^{m}\sum_{b=1}^{m} H_{ab} Y_{ab} \text{ ; a=b=1…72}$$

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$$
s.t.\begin{cases} \sum_{b=1}^{m} Y_{qb} \ge 1 \\ Max\{x_{kb}=2\},\ \ b=1\ldots72,\ k=1, a\ne k \\ y_{ij}=0或1 \end{cases}
$$

Input the distance matrix in lingo, and then solve the 0-1 integer programming problem.

The results are shown in Table 3.

Table 3

x(1,2)=1	x(2,3)=1	x(3,15)=1	x(15,27)=1	x(27,39)=1	x(39,51)=1	x(51,63)=1
x(5,17)=1	x(17,29)=1	x(29,41)=1	x(41,42)=1	x(42,43)=1	x(43,44)=1	x(44,45)=1
x(45,57)=1	x(57,58)=1	x(58,70)=1	x(6,18)=1	x(18,30)=1	x(30,29)=1	x(29,28)=1
x(28,27)=1	x(27,26)=1	x(26,38)=1	x(38,50)=1	x(50,62)=1	x(8,9)=1	x(9,21)=1
x(21,33)=1	x(33,45)=1	x(45,57)=1	x(57,56)=1	x(56,55)=1	x(55,54)=1	x(54,53)=1
x(53,52)=1	x(52,64)=1	x(12,24)=1	x(24,36)=1	x(36,35)=1	x(35,34)=1	x(34,33)=1
x(33,45)=1	x(45,57)=1	x(57,69)=1				

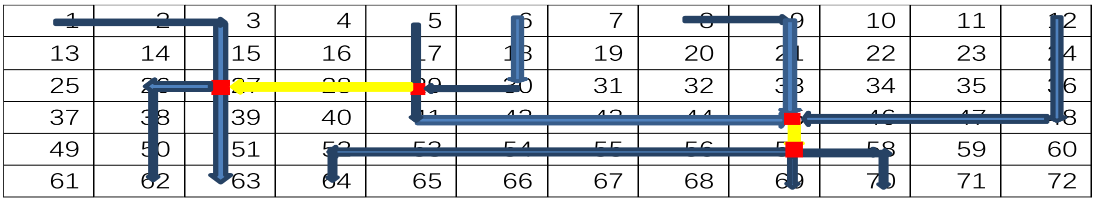

Figure 4: Optimal routing scheme

2.3 Problem 3

In problem 2, we use through holes to connect the test cases that can not use one layer of metal to complete the wiring, so that the short-circuit wires are distributed in the other two layers of metal. In problem 3, the distance between any two through holes must be greater than or equal to two grid points. Obviously, in problem 2, the distance between the rights through holes is less than two. On the basis of the second question model, we still take the shortest total distance as the objective function, By adding the condition that the through hole spacing is greater than or equal to two, several feasible schemes are screened, and the results are shown in Table 4, and the layout scheme is obtained by drawing, as shown in Figure 5.

Table 4

x(1,2)=1	x(2,3)=1	x(3,15)=1	x(15,27)=1	x(27,39)=1	x(39,51)=1	x(51,63)=1
x(5,17)=1	x(17,29)=1	x(29,41)=1	x(41,42)=1	x(42,43)=1	x(43,44)=1	x(44,32)=1
x(32,33)=1	x(33,45)=1	x(45,57)=1	X(57,58)=1	x(58,70)=1	x(6,18)=1	x(18,30)=1
x(30,29)=1	x(29,28)=1	x(28,27)=1	x(27,26)=1	x(26,38)=1	x(38,50)=1	x(50,62)=1
x(8,9)=1	x(9,21)=1	x(57,56)=1	x(55,54)=1	x(54,53)=1	x(53,52)=1	x(52,64)=1
x(12,24)=1	x(24,36)=1	x(36,35)=1	x(35,34)=1	x(34,33)=1	x(33,45)=1	x(45,57)=1
x(57,69)=1						

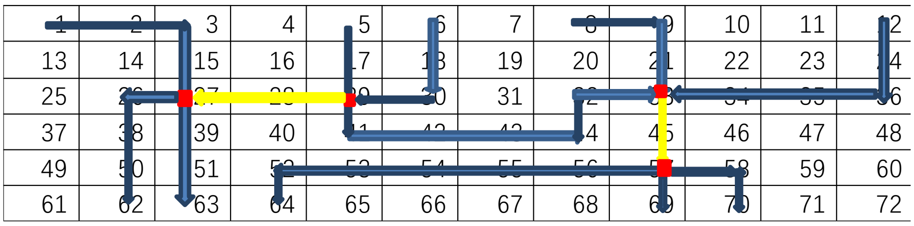

Figure 5

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3. Model Evaluation

The lingo optimization model in this paper is reasonable, which has a good guiding role for practical application, and has a certain universality. However, for the three problems with solutions, all feasible solutions are not listed, only partial decomposition is listed. And because of too much data, the data of column distance matrix is too large, and the data is not fully utilized.

References

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