Single Layer Routing based on Wire Direction Determined by Region Partition

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***Abstract*—Recently, the requirement of more IO pads becomes a very critical problem due to the increasing circuit complexity in VLSI. And both RDL routing in flip-chip designs and substrate routing in package designs utilize single-layer routing. In this paper, given a set of two-terminals nets, an efficient router is proposed to route all the nets in a single layer. Based on the minimum spanning box (MSB) of each net, the region partition is carried out. Considering two regions with intersection, sub-regions are defined by region partitioning. The initial wiring direction is carried out and the path of each routing net is assigned. Experimental results show that our proposed method has higher routability, less wire length and less CPU time compared with previous method.**

Keywords—single layer; region partition; wiring direction

1. Introduction

Recently, the requirement of more IO pads becomes a very critical problem due to the increasing circuit complexity and decreasing feature size in VLSI. RDL, redistribution layer, is introduced to redistribute the IO pads to the bump balls without changing the placement of IO pads or buffers in order that the placement can be mapped onto bump balls in flip-chip design. In flip-chip design, the routing consists of free-assignment and pre-assignment. In free-assignment, IO pads and buffers are not assigned to bump balls before routing. In pre-assignment, IO pads and buffers are assigned to bump balls. Therefore, the routing is based on the location of IO buffers and assignment of IO connections in pre-assignment. Obviously, it is more difficult to carry out the pre-assignment with constrained routing than free-assignment without any constraint. In [1], a weighted bipartite matching algorithm is applied to generate a set of IO connections between IO buffers and bump balls with A* search. However, the routability is often limited, since it's greedy. In [2], an efficient routing approach is proposed to assign all the IO connection in single layer for free-assignment. However, it costs more CPU time to route all the IO connection for pre-assignment. In [3], RDL is firstly applied to redistribute the IO pads to the bump balls without changing the location of the placed IO pads.

In package design, several substrate routing methods have been proposed. In [4][5], an efficient algorithm is applied in substrate topological routing. And planar routing is still applied in multiple routing layers for substrate routing. Single layer become important in package design, since planar routing is still the limitation of substrate routing. In [6], a feasible region assignment method is proposed. And the wiring direction of given nets can be assigned based on the routing constraints on different intersection condition of two regions in a single layer. Based on the determination of wiring direction, wiring path for each net can be assigned by diffusion the overlapping. However, wire direction determination from 4 basic intersections is not so accurate since defined wiring direction cannot be applied in some special intersection conditions and the definitions for the positions of each terminal are vague. Some special conditions could be ignored. Therefore, the routability could become low when the quantity of given nets become very large.

In this paper, given a set of two-terminals nets in a single layer, an efficient router is proposed to route all the nets without crossing. Based on the MSB, minimum spanning box, of each net, the region partition is carried out firstly. In two regions with intersection, sub-regions are defined by region partitioning. And the initial wiring direction is carried out based on the number of terminals in the intersection and the position of terminals in the nine regions. Finally, the path of each routing net can be assigned. In the experimental result, compared with Yan's method[6], our proposed method has higher routability, less wire length and less CPU time when the quantity of given nets becomes larger.

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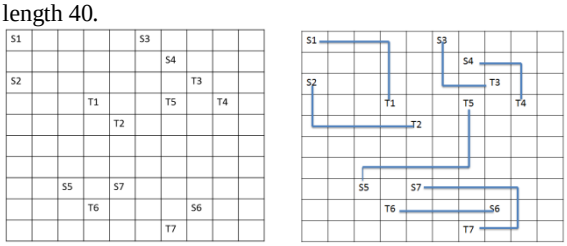
2. Problem Formulation

The routing area can be represented by a set of routing grids and the route of a signal net with just two terminals called "source" and "target" can be represented by a path consisting of horizontal and vertical segments. An arbitrary-shaped routing area can be represented by gridded map. For each net, two grids are designated as the location of source and target terminals. The path length is defined as the number of routing grids in a path. Since the routing is focused on the single layer, the crossing is not allowed in the routing.

A layout model is based on a grid-based routing(X-Y) with a single layer. Given a set of m two-terminals nets, $N = \{N_1, N_2, \dots, N_m\}$, it is assumed that m source terminals $S = \{S_1, S_2, \dots, S_m\}$, and m target terminals $T = \{T_1, T_2, \dots, T_m\}$ in N. Each source terminal S_i, $1 \le i \le m$, is connected to its corresponding target terminal T_i, to form a net, N_i.

Figure 1 illustrates an example of single layer routing where 7 two-terminal nets, $\{(S_1, T_1), (S_2, T_2), (S_3, T_3), (S_4, T_4), (S_5, T_5), (S_6, T_6), (S_7, T_7)\}$ are given. It is considered in an array of 10*10 routing grids. Figure 1(b) shows a successful routing result with wire length 40.



(a) (b)

Figure 1. Single-layer routing of 7 given nets

3. Determination of Nets' Routing Wire Direction based on Exact Region Partition

This section describes the details of proposed algorithm. It consists of three parts:

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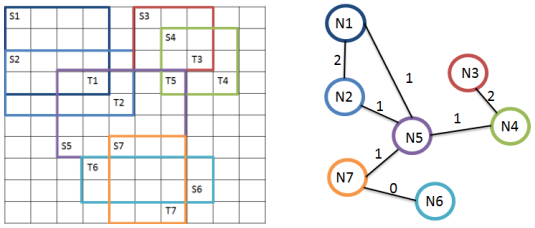
- Region assignment for each net.
- Determination of wiring direction.
- The routing of each net.

3.1 Region assignment for each net

For any net in the gridded routing model, its routing region can be defined as its MSB which is the minimum rectangle covering the two terminals. Based on the initial routing model as illustrated in Figure 1(a), MSB of each net is illustrated in Figure 2(a). The relationship among the 7 nets' regions is illustrated in Figure 2(b). And each edge is weighted based on the number of terminals in the intersection of the corresponding two regions.



(a) (b)

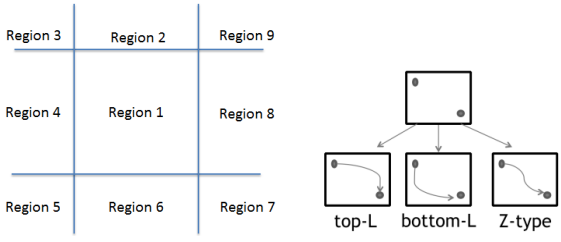
Figure 2. Region partition of all the nets

3.2 Determination of wiring direction

If there is intersection between independent regions of two terminals, a cross may occur in the wiring path. In order to successfully route all the net without crossing, the wire direction of two nets should be determined based on the intersection of corresponding regions. According to [6], four basic intersection conditions of two regions are defined from geometrical view point. Based on the 4 basic intersection conditions, the wiring direction is determined. However, wire direction determination from 4 basic intersections is not so accurate since defined wiring direction cannot be applied in some special intersection conditions and the definitions for the positions of each terminal are vague. In our proposed method, the positions of terminals are aligned on the two-dimensional array with exact coordinate. Therefore, wiring direction is determined based on the coordinates of terminals of the two pairs of nets which have intersection.

Given a pair of two terminals, there is an intersection between their regions. Let $\{(X_{is}, Y_{is}), (X_{it}, Y_{it})\}$, $\{(X_{js}, Y_{js}), (X_{jt}, Y_{jt})\}$ represent the source and target terminals' coordinates of the two nets N_i and N_j ($1 \le i \le m$, $1 \le j \le m$, m is the number of nets). And the source/target terminals of N_i and N_j are N_{is}/ N_{it} and N_{js}/ N_{jt} respectively. There is an intersection between N_i and N_j. Firstly, the intersection must be determined. Based on N_j, we assume that $min\_X_j = min(X_{js},X_{jt})$, $max\_X_j = max(X_{js},X_{jt})$, $min\_Y_j = min(Y_{js},Y_{jt})$ and $max\_Y_j = max(Y_{js},Y_{jt})$, where min means the minimum of the two parameters, max means the maximum of the two parameters.

Here, we assumed N_j's region is fixed. The N_j's region is divided into nine sub-regions based on the extension line of the N_j region's outer boundary as illustrated in Figure 3(a).



(a) (b)

Figure 3. The nine regions division and wire direction type

The whole region is divided into nine regions based on the coordinates of two-dimensional array.

$$\begin{cases} Region1 = \{x,y|\ x \in [\min\_X_j, \max\_X_j] \text{ and } y \in [\min\_Y_j, \max\_Y_j]\} \\ Region2 = \{x,y|\ x \in [\min\_X_j, \max\_X_j] \text{ and } y \ge \max\_Y_j\} \\ Region3 = \{x,y|\ x \le \min\_X_j \text{ and } y \ge \max\_Y_j\} \\ Region4 = \{x,y|\ x \le \min\_X_j \text{ and } y \in [\min\_Y_j, \max\_Y_j]\} \\ Region5 = \{x,y|\ x \le \min\_X_j \text{ and } y \le min\_Y_j\} \\ Region6 = \{x,y|\ x \in [\min\_X_j, \max\_X_j] \text{ and } y \le min\_Y_j\} \\ Region7 = \{x,y|\ x \ge \max\_X_j \text{ and } y \le min\_Y_j\} \\ Region8 = \{x,y|\ x \ge \max\_X_j \text{ and } y \in [\min\_Y_j, \max\_Y_j]\} \\ Region9 = \{x,y|\ x \ge \max\_X_j \text{ and } y \ge \max\_Y_j\} \end{cases}$$

The intersection between N_i and N_j exists, if at least one of N_{is} and N_{it} is in the Region 1, or both of them is in Region 1 or N_{is} /N_{it} are aligned in two different regions from Region 2 to Region 9 and their aligned regions must not be adjacent to each other.

Based on these intersections, we can define the relationship among each coordinate. As the number of terminals in the intersection is obtained, the wire directions for both regions can be work out based on the number of terminals in the intersection.

As illustrated in Figure 3(b), there are three basic types for wire direction. Top-L and bottom-L are defined in [6]. We introduce another basic type Z-type in our proposed method. If detour is necessary for some nets, the nets will do detour-top-L or detour-bottom-L.

3.2.1 There are 3 terminals in the intersection.

And two of the 3 terminals must belong to one region and the left one belongs to another region. Assume that the 2 terminals belong to N_i and the left one terminal belongs to N_j where the whole region of N_i is within the region1 of N_j as illustrated in Figure 3. Under this circumstance, the wire direction for N_i can be top-L or bottom-L. And the wire direction for N_j can be detour-top-L or detour-bottom-L. It is called 3-1 type.

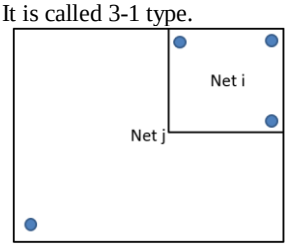


Figure 4. The condition of three terminals in the intersection

3.2.2 There are 2 terminals in the intersection.

If the two terminals in the intersection are only belong to one net and the two terminals are in Region 1 , the wire direction for N_i, can be top-L or bottom-L. It is called 2-1 type.

If one terminal belongs to N_i, and the other belongs to N_j, obviously, there are two conditions. One is that they have the same x-coordinate or y-coordinate. The other is that they have neither same x-coordinate nor same y-coordinate. Both conditions can be solved by one method. As illustrated in Figure 5(a), one type of intersections is shown. And the two terminals in the intersection will be regarded as one terminal. An x-y coordinate is drawn based on this new terminal as illustrated in Figure 5(b). If the other two terminals are aligned in diagonal area as shown in Figure 5(b), both of the two nets can be routed without detouring. Both of the nets can be routed by top-L and bottom-L respectively as shown Figure 5(c). This is called 2-2 type.While if the two terminals are in aside as illustrated in Figure 5(d), one of the nets will do detour-top-L or detour-bottom-L direction. This is called 2-3 types.

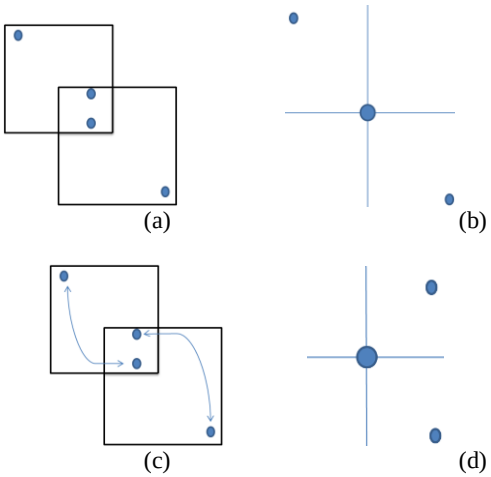


Figure 5. The condition of two terminals in the intersection

3.2.3 There are only one terminal in the intersection.

The net whose terminal is in the intersection can do top-L or bottom-L. If N_i's terminal is in the intersection, N_j's wiring direction is based on the position of N_j's terminals and N_i's another terminal which is out of the intersection. If N_i's another terminal is alignd in Region 3 or Region 9, N_j's wiring direction is bottom-L as illustrated in Figure 6(a). This is called 1-1 type. If N_i's another terminal is alignd in Region 5 or Region 7, N_j's wiring direction is top-L as illustrated in Figure 6(b). This is called 1-2 type. If N_i's another terminal is alignd in Region 4, N_j's wiring direction is top-L when N_j's terminals are top-left and bottom-right as illustrated in Figure 6(c) and the direction is bottom-L when N_j's terminals are top-right and bottom-left. This is called 1-3 type. If N_i's another terminal is aligned in Region 8, N_j's wiring direction is top-L when N_j's terminals are bottom-left and top-right and the direction is bottom-L when N_j's terminals are bottom-right and top-left. This is called 1-4 type. If N_i's another terminal is alignd in Region 2, N_j's wiring direction is bottom-L as illustrated in Figure 6(d). This is called 1-5 type. If N_i's another terminal is aligned in Region 6, N_j's wiring direction is top-L. This is called 1-6 type.

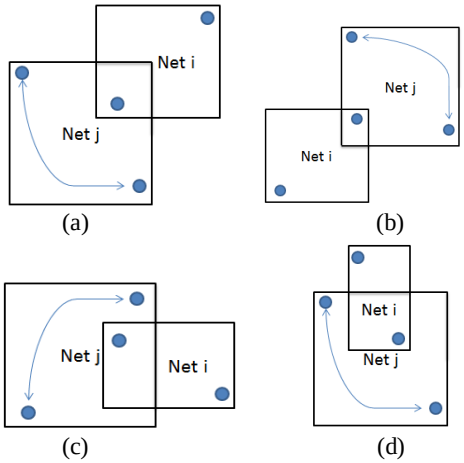


Figure 6. The condition of one terminal in the intersection

3.2.4 There are no terminals in the intersection.

If N_{is}/N_{it} are aligned in Region2/Region6 or Region4/Region8, The wiring direction of N_i can be either top-L or bottom-L. And the wiring direction of N_j must be detour-top-L or detour-bottom-L as illustrated in Figure 7(a). This is called 0-1 type. Another condition is that N_{is}/ N_{it} must be aligned in different regions among Region2, Region4, Region6 or Region8. And the pairs of the terminals aligned regions can be Region2/Region4, Region2/Region8, Region4/Region6 and Region6/Region8. If their aligned regions are Region2/Region4 or Region2/Region8, the wiring direction of N_j must be bottom-L and the wiring direction of N_i can be top-L or bottom-L as illustrated in Figure 7(b). This is called 0-2 type. If their aligned regions are Region4/Region6 Region6/Region8, the wiring direction of N_j must be top-L and the wiring direction of N_i can be top-L or bottom-L as illustrated in Figure 7(c). This is called 0-3 type.

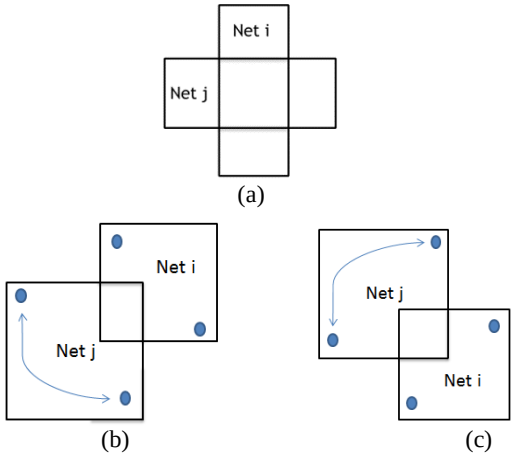


Figure 7. The condition of no terminals in the intersection

Based on the determination of wiring direction and the relationship as illustrated in Figure 2(b), the new generated topological weighted relationship with direction type is as illustrated in Figure 8(a). And the corresponding wiring directions are assigned to each net as illustrated in Figure 8(b).

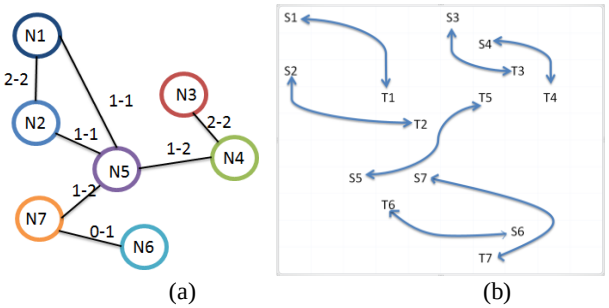


Figure 8. The relationship between each region and the wiring direction

3.3 The routing of each net

After determination of the wiring direction of all the routing net in a single layer, a sequential assignment process is executed as follows. The sequence is based on the number of terminals in intersection. The larger the number is, the higher priority they will have. Since the complexity of routing will be higher, if there are more terminals in the intersection. Therefore, the two regions with the intersection where there are two terminals routed firstly. Then, the two regions with the intersection where there are one terminal routed. Finally, the two regions with the intersection where there are no terminal routed. For the regions whose relationship are with the same terminals in the intersection, this kind of region will combine all the types and determine the final direction. And there is a net assigned with both top-L and bottom-L. Therefore, usually, its direction is Z-type to avoid

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crossing. Based on Figure 8(a), the pairs of N1/N2 and N3/N4 will be routed firstly. N1's direction is top-L and N2's direction is bottom-L. N3's direction is bottom-L and N4's direction is top-L. And the left nets are N5, N6 and N7. N5's relations are all with one terminals in the intersection. Therefore, N5's direction is Z-type. N6's direction is bottom-L and N7's direction is detour-top-L. Therefore, the initial direction for each net is as illustrated in Figure 8(b). Depend on the direction of each net in Figure 8(b), the routing path of each net is as illustrated in Figure 9.

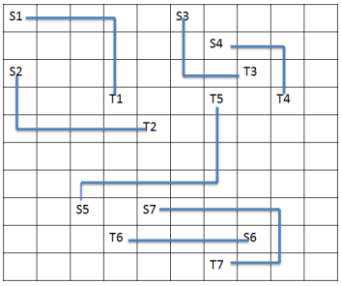

Figure 9. Routing path of each net

4. Experimental Results

To verify the effectiveness of the proposed method, we implemented our method and the method in [6] by using C language, compiled on MinGW Developer Studio 2.06, and executed on a PC with 2.66GHz Intel Core 2 CPU and 2GB RAM. There are 7 test cases. All of them are randomly generated in single-layer routing. And the result is illustrated in Table I.

In this table, "# Routing grids" denotes the dimension of routing grids in a single-layer routing, "#Routing nets" denotes the number of given routing nets, "#Routed nets" denotes the number of successfully routed nets, "Total wirelength" denotes the total wirelength of all the routed nets, "CPU time" is the CPU time which successfully routing all the nets costs.

From Table I, compared with Yan's method[6], our proposed method has higher routability and less CPU time when there are a large quantity of given nets.

5. Conclusions

Based on the MSB of each net, the region partition is carried out. In two regions with intersection, a nine-region partition is generated. And the initial wiring direction is carried out based on the number of terminals in the intersection and the position of terminals in the nine regions. Finally, the path of each routing net can be assigned. Our proposed method has higher routability, less wire length and less CPU time when there are a large quantity of given nets.

Reference

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Table I

Given data			J-T Yan's method			Our proposed method		
Example	#Routing Grids	#Routing Nets	#Routed Nets	Total wirelength	CPU time	#Routed Nets	Total wirelength	CPU time
1	10*10	7	7	40	0.06	7	40	0.06
2	15*15	20	20	123	0.17	20	121	0.21
3	20*20	65	65	375	0.36	65	368	0.46
4	40*40	180	180	1134	0.67	180	1110	0.65
5	80*80	545	542	3415	1.74	545	3398	1.70
6	160*160	1523	1505	11207	4.72	1523	10746	4.63
7	250*250	4436	4402	34748	12.21	4432	33627	11.83

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