Routability Crossing Distribution and Floating Terminal Assignment of T-type Junction Region

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Abstract

In this paper, two routability crossing distribution problems based on the non-crossing relations, vertical constraint relations and geometry relations are proposed to improve routing performance of one T-type junction region. For the routability problem, a routability ordering graph can be built to decide a net ordering on the boundary in $O(n^2)$ time. Furthermore, for the routability quota problem, if the number of crossings for the routability problem is more than the quota, the net ordering in the routability problem must to be adjusted by a net interchange operation to satisfy the quota requirement in the routability quota problem in $O(n^2)$ time. Since a net ordering is obtained in the routability problem or the routability quota problem, the global nets will be assigned onto the boundary in $O(n)$ time by interleaving vacant terminals between any pair of global nets for the floating terminal assignment of the boundary.

1. Introduction

In macro cell design style or building block layout[1], the layout problems for the placement and routing can be solved in the following steps[2] : placement, global routing, routing region definition and ordering assignment(RRDAOA), detailed routing. In the placement phase, according to area or performance requirements, all of the macro cells can be placed on fixed positions and the routing area between any pair of macro cells can be assigned for the routing phase. In the routing phase, all of the routing nets will be globally assigned within the routing area in the global routing phase. Furthermore, the routing area can be partitioned into channels, switchboxes, or L-shaped channels, and the regions can be assigned the orders to guarantee a safe routing ordering in the RRDAOA phase. Finally, the channels, switchboxes, and L-shaped channels can be routed by a channel router, a switchbox router and a L-shaped channel router, respectively in the detailed routing phase. However, the routing nets in one region are not be assigned a net ordering in the global routing phase, and the net ordering in the region will be decided by a channel router or a switchbox router in the detailing routing phase.

Consider the macro cell placement shown in Fig. 1 and suppose that the regions A, B, C, and D are all to be routed as channels. From the viewpoint of channel definition, because the terminals in region B are not fixed, region A must be routed before region B. For the same reason, region B must be routed before region C, region C must be routed before region D, and region D must be routed before region A. The iterative phenomenon of precedence relations can construct a precedence cycle, and the cyclic constraint is named a cyclic channel precedence constraint. If one macro cell placement is with the existence of any cyclic channel precedence constraint, the routing area cannot only be decomposed into channels. In general, switchboxes [3-4] or L-shaped channels are applied to release these cyclic channel precedence constraints in a macro cell placement.

Fig. 1. A cyclic channel precedence constraint.

Under the condition of a cyclic channel precedence constraint, we can refer again to the macro cell placement shown in Fig. 1. If a switchbox is introduced to release the cyclic precedence constraint, the height of region A can be estimated according to the routability requirements, and the net ordering of the boundary between region A and region B must be pre-assigned. Then region B, region C and region D will be sequentially routed as channels in that order. Finally, region A with a fixed area and fixed terminals on three of its four sides is routed by a switchbox router. However, the successful routing still depends on the switchbox routing and the ordering assignment of the global nets on the T-type junction region. In addition to increasing routability of the defined switchbox, a better ordering assignment of the global nets will avoid the reconstruction of the placement and the rip-up and reroute in the routing phase. In general, the ordering assignment of the global nets is called the crossing distribution problem. Besides detailed routing in macro cell layout style, the crossing distribution problem for routing nets is crucial in certain architectures of programmable gate arrays[5] or in routing of analog and high speed circuits where wires can run in parallel for only a limited distances and additional restrictions on topology of wires.
In [6], by the topological sorting and perfect matching techniques, Marek-Sadowska and Sarrafzadeh proposed an \( O(m^2 + m\sqrt{n}) \) algorithm for the quota problem to distribute crossings among all of the regions in the placement. The quota of each region was decided by the routability considerations of the region. However, each region was not further discussed in detail how to calculate the quota. It is difficult to imagine the relation between the quota and the routability requirements of one region. According to the observation in the RRD DAOA phase, it is not necessary to assign crossings to all of the regions simultaneously. It is sufficient to process one boundary between two regions at a time in the order defined by the RRD DAOA phase. In [7], by using computational geometry techniques, D. C. Wang and C. B. Shung proposed a \( O(n \log n) \) algorithm for the quota problem, a \( O(n^2) \) algorithm for the membership problem and a \( O(n^2) \) algorithm for the combination problem to distribute crossings into two adjacent regions. However, the algorithms didn’t still consider how the quota and membership were obtained from the routability requirements. Since the crossing distribution is to distribute crossings to regions to improve routing performance, the crossing distribution problem must consider the routability instead of the quota and membership.

2. Problem Description and Definitions

For one T-type junction region, the region can be divided into the top part, R1, and the bottom part, R2, by one boundary, B. One T-type junction region and its division can be shown in Fig. 2. The crossing distribution for the floating terminal assignment is to arrange a net ordering of global nets, which intersect the boundary, B, and assign the global nets onto the boundary, B, to improve routing performance of the T-type junction region. Thus, the crossing distribution can be separated into two phase: net ordering and net assignment. In the net ordering phase, a net ordering of global nets will be decided. In the net assignment phase, the global nets based on the net ordering will be assigned onto the floating terminals on the boundary B.

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Fig. 2 A T-type junction region for the crossing distribution.

Let us consider that all of the nets, Net, are two-terminal nets. The nets in the crossing distribution problem must intersect the boundary B, i.e., one terminal is located on R1 and the other is located on R2. By dividing the boundary B, two terminal lists, TOP and BOT, are derived, where each represents the ordering of terminals. A net i has a top terminal T(i) and a bottom terminal B(i). For any pair of nets, a forced crossing that cannot be avoided is defined as follows: two nets i and j has a forced crossing (i, j) if B(i) < B(j) and T(i) > T(j) or B(i) > B(j) and T(i) < T(j), where s < t (s > t) mean that s is located on t’s left (right). The crossing (i, j) is unordered, i.e., (i, j) = (j, i). Let us define the set of forced crossings, S, by

\[ S = \{(i, j) \mid B(i) < B(j) \land T(i) > T(j) \lor B(i) > B(j) \land T(i) < T(j)\} \]

Other crossings that can be avoided are called redundant crossings. In general, the routability crossing distribution for one T-type junction region is to determine net ordering and assign net position at the boundary such that

Objective 1: No redundant crossings are introduced.

Objective 2: Forced crossings are distributed between two regions to improve routing performance.

Objective 3: Global nets are assigned onto the boundary to improve routing performance.

Since the crossing distribution problem is solved to improve routing performance, it is necessary to focus on the routing requirement of one T-type junction region.Basically, the top and bottom parts, R1 and R2, of one T-type junction region are one channel and one switchbox, respectively in the RRD DAOA phase. Traditionally, the channel density, vertical constraint graph and vertical constraints can be applied to estimate routing performance of one channel. If the channel density is less, the vertical constraint graph is simpler and the number of vertical constraints is less, one channel can be routed in smaller wire length, less via and smaller area. For the routing performance of one T-type junction region, these different relations of routing requirements can be defined as follows and applied to the following routability crossing distribution problems.

As mentioned above, objective 1 of the crossing distribution is to guarantee that no redundant crossings are introduced. It is well known that redundant crossings will yield redundant vias in the routing phase. Thus the non-crossing relations will be defined to restrict the appearance of redundant crossings in a crossing distribution.

Definition 1: (Non-Crossing Relations, N) For the terminal lists, TOP and BOT, of one T-type junction region, one non-crossing relation i --> j is defined if \( B(i) < B(j), (i, j) \notin S \) and there exists no k such that \( B(i) < B(k) < B(j) \) and \( T(i) < T(k) < T(j) \).

Furthermore, to guarantee the routability of region R2 representing one switchbox, the vertical constraints in R2 must be avoided. Thus the vertical constraint relations will be defined to restrict the appearance of vertical constraints in R2.

Definition 2: (Vertical Constraint Relations, V) For the bottom part, R2, of one T-type junction region, one vertical constraint relation i --> j is defined if \( i, j \notin S \), and two terminals, i and j, are located on the same routing column, where i is located on left terminals of R2 and j is located on right terminals of R2.

For region R1 of one T-type junction region, the region can be further divided into subregions R11, R12 and R13. In order to reduce total wire length and minimize the channel density in R12, the geometry relations of the terminals in R11, R12 and R13 will be defined to improve routing performance in R12.

Definition 3: (Geometry Relations, G) For the regions R11, R12 and R13, one geometry relation i --> j is defined if terminals i and j correspond to one of the three conditions:
Condition 1: terminal i is in R11, terminal j is in R12 and (i, j) ∈ S.
Condition 2: terminal i is in R11, terminal j is in R13 and (i, j) ∈ S.
Condition 3: terminal i is in R12, terminal j is in R13 and (i, j) ∈ S.

In general, the non-crossing relations guarantee that no redundant crossings are introduced and the vertical constraint relations improve routability in R2. Thus, the non-crossing relations and the vertical constraint relations are fully necessary for the crossing distribution problem. However, it is possible that the geometry relations will conflict with the vertical constraint relations and the non-crossing relations. Hence, the geometry relations are not fully necessary in the crossing distribution problem. The routability crossing distribution problem is to apply the maximal geometry relations to improve routing performance of one T-type junction region. The routability crossing distribution problems will be introduced and modeled as follows:

Routability Problem: Given one T-type junction region, R1 and R2, the boundary, B, and a set of two-terminal nets, Net, the routability objective is to find a feasible assignment of global nets on the boundary B such that the non-crossing relations and the vertical constraint relations are fully applied and the maximal geometry relations are applied to improve routing performance of the T-type junction region.

For one T-type junction region, the region can be divided into a channel and a switchbox by assigning the floating terminals on the boundary in the RRDAOA phase. It is well known that switchbox routing is more difficult than channel routing. On the other hand, in the RRDAOA phase, the channel height is adjustable and the switchbox height is not adjustable in a safe ordering. In order to route successfully the T-type junction region, a small quota K (even to 0) will be selected to guarantee that the divided switchbox can be successfully routed. Thus, the routability quota crossing distribution problems will be introduced and modeled as follows:

Routability Quota Problem: Given one T-type junction region, R1 and R2, the boundary, B, a set of two-terminal nets, Net, and an integer quota K, the routability objective is to find a feasible assignment of global nets on the boundary B such that at most K crossings are pushed to R2, the non-crossing relations and the vertical constraint relations are fully applied, and the maximal geometry relations are applied to improve routing performance of the T-type junction region.

3. Routability Crossing Distribution for Floating Terminal Assignment

The routability crossing distribution can be applied to assign floating terminals of one T-type junction region. In general, the assignment can be divided into two phase: net ordering and net assignment. Based on the routing constraints and region routability, a net ordering of the global nets can be arranged to improve routing performance in the net ordering phase. Two routability crossing distribution problems are proposed to decide a net ordering. One is a pure routability problem. Based on the non-crossing relations, vertical constraint relations and geometry relations, a net ordering is obtained by a modified topological sorting for a routability ordering graph. The other is a routability quota problem. In the RRDAOA phase, the T-type junction region will be separated into a channel and a switchbox. To guarantee that the switchbox be successfully routed, the quota K in the switchbox must be estimated. Based on the crossing distribution of the previous net ordering in the routability problem, if the number of crossings in R2 is more than the quota K, the net ordering must be modified to satisfy the quota restriction by a net interchange operation.

Since a net ordering of the global nets has been decided in the net ordering phase, the global nets must be distributed to the boundary B to assign floating terminals of B in the net assignment phase. If the number of global nets corresponds to that of floating terminals, the global nets will be assigned in this order. On the other hand, if not, the global nets will be assigned by adding vacant terminals between any pair of global nets to minimize the number of vertical constraints in R12 without increasing the length of the longest path in R1.

3.1. Net Ordering for The Routability Problem

For the routability of one T-type junction region, according to the non-crossing relations, vertical constraint relations, and geometry relations, a directed routability ordering graph G = (V, A) will be built, where v in V represents a global net and e in A represents a non-crossing relation, a vertical constraint relation or a geometry relation. The routability ordering graph of the T-type junction region in Fig. 2 can be shown in Fig. 3.

Fig. 3 A routability ordering graph.

Due to the geometry relations to be introduced into a routability ordering graph, the graph may be cyclic. The routability problem is to apply the maximal geometry relations to improve routing performance of one T-type junction region. Hence, if a routability ordering graph is cyclic, it is not necessary to apply all of the geometry relations to improve routing performance of one T-type junction region. Using the maximal geometry relations, a net ordering of the global nets is still obtained by a modified topological sorting. In the modified topological sorting, one vertex with no predecessor will be selected to be ordered and then deleted from the graph if a routability ordering graph is not empty. On the other hand, if the graph is not empty and there exists no vertex with no predecessor, one vertex with only geometry relation predecessors will be selected to be ordered and then deleted from the graph. Finally, a routability net ordering can be decided by the modified topological sorting. It is well known that if the
3.2. Net Ordering for The Routability Quota Problem

By a modified topological sorting, a net ordering is obtained in the routability problem. If the number of crossings in R2 is more than the quota K, the net ordering must be modified to satisfy the quota restriction in the routability quota problem. Consider that a net ordering (N1, N2, ..., Nn) is obtained in the routability problem, where n is the number of global nets. It is known that if B(Ni) > B(Ni+1) in the net ordering, there exists one forced crossing in R2. Hence, if the orders of nets Ni and Ni+1 are interchanged, the crossing between nets Ni and Ni+1 in R2 will be pushed into R1. To satisfy the quota K, some net interchanges will be done to reduce the number of crossings in R2 for the routability quota problem. The routability quota crossing distribution which is obtained from the routability crossing distribution by a net interchange operation.

Since the quota K is known and a net ordering is decided in the routability problem, the number of crossings in R2 will be easily calculated. In the interchange, the iterative number is O(1), and the time complexity of finding a pair of nets Ni and Ni+1 is in O(n) time. Hence, the time complexity of the algorithm is in O(n) time, and the routability quota crossing distribution is solved in O(n^2) time.

3.3 Net Assignment

Since a net ordering of the global nets is obtained in the net ordering phase, the global nets based on the net ordering must be assigned onto the boundary B for the floating terminal assignment of the boundary B. In the net assignment phase, there are fixed net terminals and vacant terminals in the top boundary of R12, and the global nets and vacant terminals will be assigned onto the bottom boundary of R12. In general, the routability objective in the net assignment phase is to minimize the number of vertical constraints in R12 without increasing the length of the longest path in the vertical constraint graph for R1. Let Tn (Bn) and Tn (Bn) be the number of net terminals and vacant terminal on the top(bottom) boundary of R12, respectively, and Nb is the number of terminals on the boundary B.

Clearly, Nb = Tn + Tn = Bn + Bn. If Tn + Bn < Nb, according to the distribution of vacant terminals on the top boundary of R12, the global nets based on a net ordering can be assigned by interleaving vacant terminals such that no vertical constraint is introduced in R12. On the other hand, if Tn + Bn > Nb, there are at most l Tn - Bn > 1 vertical constraints based on the routability objective to be produced in R12, and these vertical constraints will not increase the length of the longest path in the vertical constraint graph for R1. The net assignment for the floating terminal assignment of the boundary B can be obtained by minimizing the number of vertical constraints in R12. Since Nb and (N1, N2, ..., Nn) are known, the number of net terminals in the top terminal list of R12 will be easily calculated. In the net assignment the global nets in a net ordering are assigned onto the boundary B by a sequential checking operation. Hence, the time complexity of the algorithm is in O(n) time, where n is the number of global nets. The T-type junction region in Fig. 2 can be routed in the routability crossing distribution and the routability crossing distribution with the quota K = 1 and shown in Fig. 4 and Fig. 5, respectively.

4. Conclusions

Based on the non-crossing relations, vertical constraint relations and geometry relations, two routability crossing distribution problems, routability problem and routability quota problem, are proposed to improve routing performance of one T-type junction region in O(n^2) time. Since a net ordering is obtained in the routability problem or the routability quota problem, the global nets will be assigned onto the boundary B by interleaving vacant terminals between any pair of global nets for the floating terminal assignment of the boundary B. It is proven that the time complexity of the floating terminal assignment is in O(n) time.

References