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A Fast Congestion Estimator for Routing with Bounded Detours

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Abstract

Congestion estimation is an important issue for the success of the VLSI layout. Fast congestion estimation provides an efficient means to adjust the placement and wire planning. A probabilistic model of interconnections enables designers to quickly predict routing congestion. We propose a powerful and fast estimation approach which allows wires to have bounded-length detours to bypass congestions. The method is more realistic and precise than the previous work. The experimental results demonstrate the effectiveness of the method on routing benchmarks.

Index Terms: VLSI Routing, Probabilistic Methods, Estimation.

1. Introduction

As deep-submicron fabrication technology advances, billion-transistor chips will be feasible in future. Estimation of the routing area becomes a crucial issue for a hierarchical design process and a necessity for top-down design styles [2]. With varieties of intellectual property (IP) from multiple sources, the estimation of the wire area becomes a more difficult issue in the development of the giga-transistor chip [1, 2, 4]. Fast congestion estimation provides an efficient means to adjust the placement and wire planning [1, 2, 4, 5, 7, 8].

With sizes on the order of hundreds of cells and thousands of connections, a probabilistic model of interconnections will enable designers to quickly compute estimates of the routing congestion. There has been some work on probabilistic models. Lou et al. [7] presented a fast probabilistic estimation for congestion. They assumed each net uses the shortest route and each possible route has the same usage probability. Base on such assumption, they estimate the congestion for the routing area.

In practice, the placement and routing problems are hardly solved optimally due to their computational complexity. The previous probabilistic approaches are not sufficient accurate as the shortest routes are merely considered in their restricted models. A more precise prediction should incorporate congestion-related detouring in the model to reflect the actual practice. In this paper, we propose a novel model where wires are allowed to have bounded-length detours to bypass congestions. We present a probabilistic method to estimate the congestion of interconnect wires. The method is more realistic and precise than the previous work. The experimental results demonstrate the effectiveness of the method on routing benchmarks.

2. Problem Formulation

Given a set of nets, the routing area can be decomposed into *grids*. An *edge* is a border between two grids. The *capacity* of an edge is the number of available tracks crossing the edge and the *density* of an edge is the number of routes crossing the edge. Given a set of nets, we estimate the density of each edge of the routing area. We restrict our discussion on two-terminal nets. The model can be extended to handle the case for multi-terminal nets by using rectilinear Steiner tree or minimum spanning tree.

Without loss of generality, we assume that the terminals are located at the lower left and upper right grids. The lower left terminal is the *start terminal* and the upper right terminal is the *end terminal* of the net. The *direction* of the route is from the start terminal to the end terminal. A *forward segment* is a route segment which goes continuously up or right. A *reverse segment* is a route segment which goes continuously down or left.

Since we do not restrict the net route with the shortest length, the routes may not be monotonic. We use the coordinate on the grid. The coordinate of the grid containing the start terminal is assigned as (0, 0) and the coordinate of the grid containing the end terminal is assigned as (m, n), $m \geq 0$ and $n \geq 0$, as shown in Fig 1. If a route contains reverse segments, it will increase the total wire length, thus increasing delay. To limit the wire length, we make the following assumptions for each route.

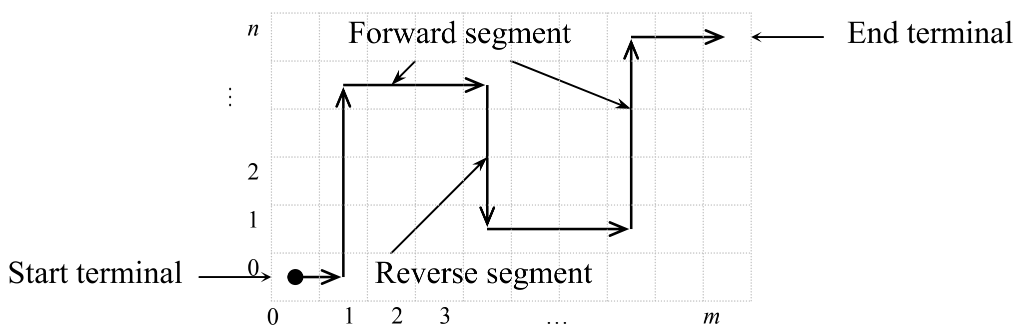


Fig 1. A non-monotonic path from (0, 0) to (m, n).

Assumptions:

(i) The route contains only one reverse segment.

(ii) The reverse segment is a straight line.

(iii) The length of the reverse segment is bounded by no more than d+1 grids, $d \geq 0$ is an integer.

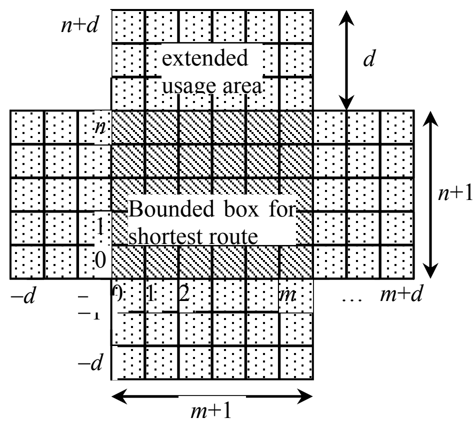


Fig 2. The expanded routing area for non-monotonic route.

By allowing the route to go down or left, the legal usage area is actually extended. As shown in Fig 2, (m, n) is the end terminal coordinate and $d+1$ is the bound of the reverse segment. This models the actual layout where the shortest route is not always achievable.

Consider the *dual* graph of the grid model [7] as the *routing mesh model* in Fig 3. Each grid is represented by a node and the line segment connecting two adjacent nodes represents the line between two adjacent grids. The coordinate of each grid in the grid model is that of the corresponding point in the routing model. In the routing mesh model, a *unit line* is the line connecting two adjacent nodes. The *length* of the route is the number of unit lines covered by the route. Node (0, 0) is the *start point* of the route and node (m, n) is the *end point* of the route. Both the start and end points are *extreme points* of the route.

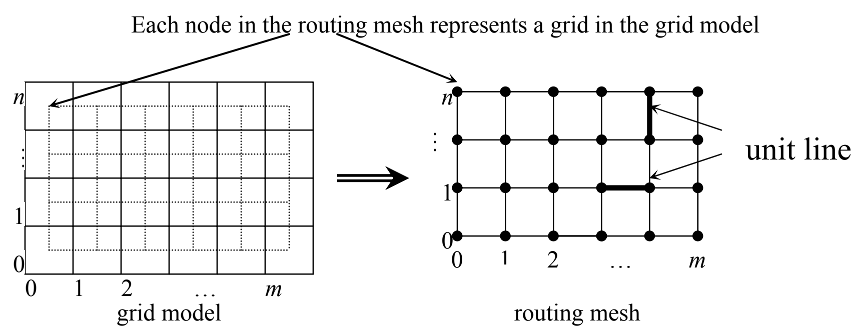


Fig 3. The grid model and its dual mesh model.

Since the reverse segment of the route can go through no more than $d+1$ grids, the length of the reverse segment is no more than d in the routing mesh model. The capacity and density of each edge in the grid model becomes the capacity and density of the corresponding unit line in the routing mesh model, respectively.

Problem Statement:

Given a set of nets in the routing mesh model, estimate the density of all the edges for all routes satisfying the following constraints:

i) The route contains only one reverse segment.

ii) The reverse segment is a straight line.

iii) The length of the reverse segment is bounded by no more than $d+1$ grids, $d \geq 0$ is an integer.

3. Experimental Results

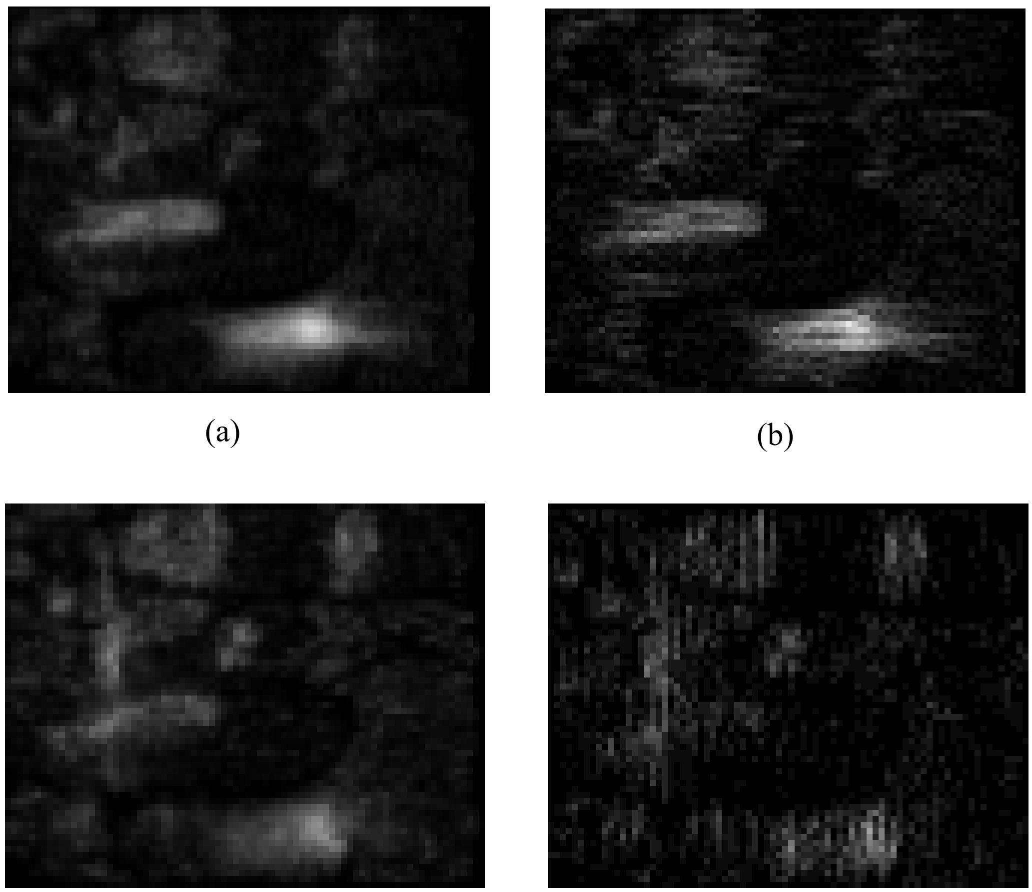
Our estimator is implemented in C and the experiments are run on a machine Pentium III 1G Hz with 256M memory. The benchmarks are obtained from Prof. M. Sarrafzadeh's group at UCLA [3]. We compare our estimated results to those produced by the global router developed by the research group of Prof. M. Sarrafzadeh at UCLA [3].

In Table 1, we summarized the results for five benchmarks. For each benchmark, we tested it on our estimator, the estimator without detour and the global router. The density is divided into four ranges according to the unit line capacity. We count the number of unit lines whose density are in each range. For instance, in benchmark 2, the capacity for each vertical unit line is 20, we divide the density of vertical unit line into four ranges: 0-5, 6-10, 11-15, and 15-20. The global router outputs 736 unit lines whose density is between 6 and 10, the estimation without detour predicts 561 such unit lines while our method predicts that there are 704 such unit lines. Our prediction is very close to the outcome of a real global router while the time used by the estimator is dramatically smaller.

Table 1

Benchmarks		Vertical Unit lines				Horizontal Unit lines				
Benchmark 1 # of nets: 9874 routing area: 80×64 vertical capacity: 22 horizontal capacity: 32	Density range	0-5	6-10	11-15	16-22	0-7	8-14	15-21	22-34	Run time (s)
	Global router	4870	237	13	0	4777	274	57	12	64
	Analysis without detour	4974	142	4	0	4480	452	111	77	1
	Analysis with detour	4787	312	21	0	4798	264	49	9	2
Benchmark 2 # of nets: 15583 routing area: 96×64 vertical capacity: 20 horizontal capacity: 33	Density range	0-5	6-10	11-15	16-20	0-5	6-10	11-15	16-23	Run time (s)
	Global router	5273	736	125	10	4732	1217	168	27	144
	Analysis without detour	5517	561	62	4	5036	978	121	9	1
	Analysis with detour	5288	704	144	8	4841	1143	149	11	2
Benchmark 3 # of nets: 19386 routing area: 128×64 vertical capacity: 20 horizontal capacity: 23	Density range	0-5	6-10	11-15	16-20	0-8	9-16	17-24	25-33	Run time (s)
	Global router	7931	257	4	0	7508	663	21	0	238
	Analysis without detour	8061	131	0	0	7661	524	7	0	1
	Analysis with detour	7901	291	0	0	7716	476	0	0	2
Benchmark 4 # of nets: 26735 routing area: 192×64 vertical capacity: 21 horizontal capacity: 32	Density range	0-5	6-10	11-15	16-21	0-7	8-14	15-21	22-32	Run time (s)
	Global router	11724	558	6	0	11886	402	0	0	466
	Analysis without detour	12041	247	0	0	12061	227	0	0	1
	Analysis with detour	11881	407	0	0	12014	184	0	0	2
Benchmark 5 # of nets: 28796 routing area: 256×64 vertical capacity: 14 horizontal capacity: 28	Density range	0-3	4-6	7-9	10-14	0-6	7-12	13-18	19-28	Run time (s)
	Global router	14052	2167	156	9	14769	1519	96	0	866
	Analysis without detour	15215	1105	61	3	15164	1166	54	0	2
	Analysis with detour	13988	2281	112	3	15167	1189	28	0	4

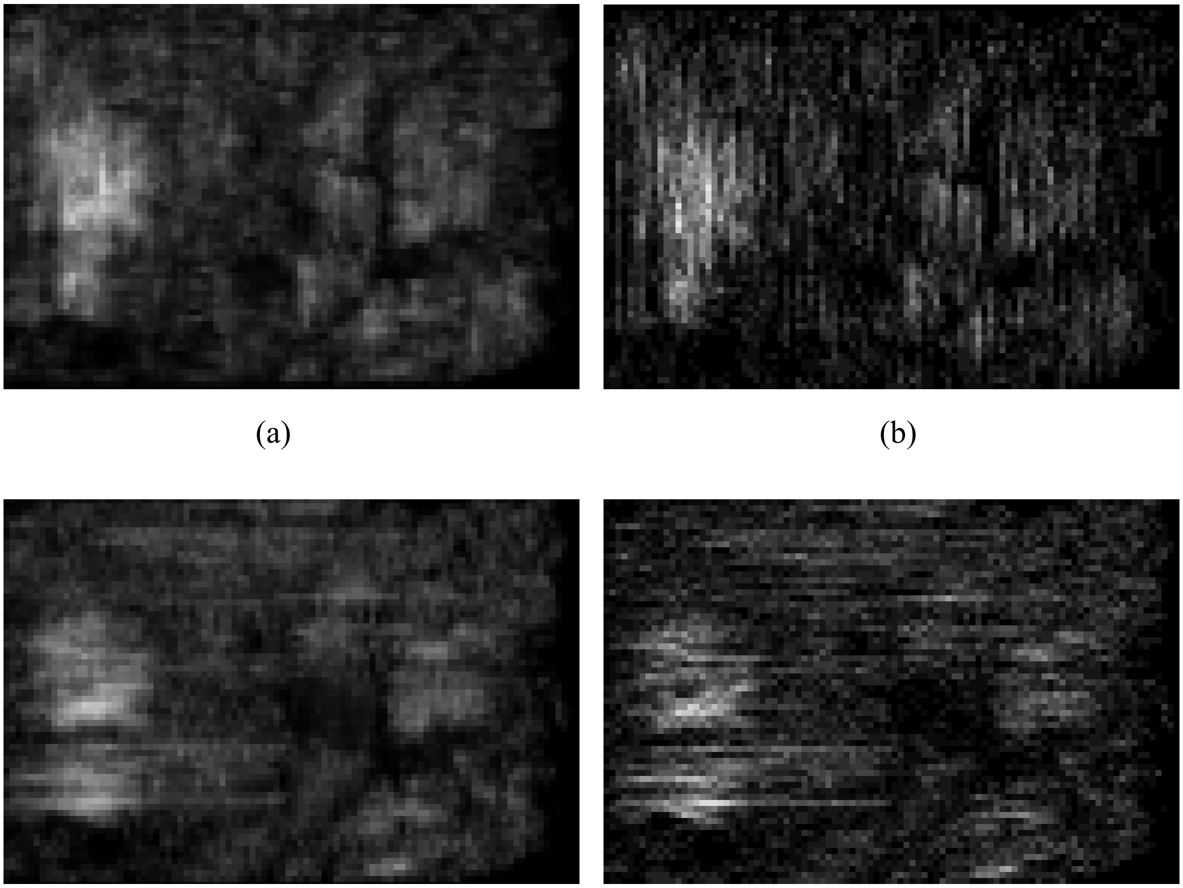
Fig.12 and Fig.13 illustrate the density map for Benchmarks 1 and 2, respectively. The brighter color represents a higher density. The density predicted by our method is very close to that predicted by the global router.



(a) (b) (c) (d)

(a) Vertical density predicted by our method. (b) Vertical density predicted by global router.
(c) Horizontal density predicted by our method. (d) Horizontal density predicted by global router.

Fig 12. Congestion maps for Benchmark 1.



(a) (b) (c) (d)

(a) Vertical density predicted by our method. (b) Vertical density predicted by global router.
(c) Horizontal density predicted by our method. (d) Horizontal density predicted by global router.

Fig 13. Congestion maps for Benchmark 2.

4. Current Work

Our current work is to extend our approach by incorporating other design constraints:

1) Bounded number of bends
2) Relaxed detour constraints.

5. References

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