A New Effective Congestion Model in Floorplan Design[1]

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Abstract

In this paper, we provide a new efficient and accurate congestion model embedded into a floorplanner to estimate the congestion of floorplans. It is based on probabilistic analysis and a new concept of Irregular-Grid which uses the routing information to determine the evaluating regions instead of fixed-size grids. Three complete experiments are performed and the experimental results show the correctness, accuracy and efficiency of our new congestion model.

1. Introduction

Advances in the deep-submicron technology have brought many changes and challenges to the targets of design methodologies. Wire congestion will deteriorate design performance because of detoured nets and even could lead to unroutable solutions. It also causes the timing-related problems because detoured routes result in mismatch between preroute and postroute timing models. Therefore measuring congestion earlier in the design cycle is necessary and may helps saving a lot of time and resources. A good model for congestion estimation should be accurate enough to reflect the real post-routing result and fast enough to be embedded into the iterative algorithms for searching the optimal floorplan solution.

Previous researches address congestion model in floorplanning and placement stage. They could be roughly divided into three categories: empirical models[5], global router based models[6] and probabilistic analysis based models[1][3][4]. It has been verified experimentally that probabilistic analysis is a quite practical method to predict the wire congestion before routing. In this paper we propose a new congestion model which is based on the concept of probabilistic analysis but modifies the original weakness of fixed-size evaluating grids by using irregular-size evaluating grids. Therefore the evaluating time will be saved to focus on the probably more congested locations instead of everywhere uniformly to make the estimation more precise and efficient. In order to maintain the computing complexity in constant time, we induced well-approximating formulas to compute the probability for a net passing through an irregular-size grid rapidly. Finally experimental results validate our theoretical work and our model performs well in congestion estimating of floorplans to be applied to the routability-driven floorplanner.

This paper is divided into six sections. In section 2, the formulation of the congestion estimating problem in floorplanning is given. In section 3, we introduce the tarditonal congestion model using probabilistic analysis and fixed-size evaluating grids, and also conduct some definitions and formulas. In section 4, the details of our new congestion model will be described and explained completely. Three different experiments are designed and performed to demonstrate the correctness, accuracy and efficiency of our new model. The experimental results are shown in section 5. Finally, the conclusion is given.

2. Problem Formulation

Given a set of m modules $M_1, M_2, \ldots, M_m$ and a set of n 2-pin nets $N_1, N_2, \ldots, N_n$, the objective of floorplanning is to obtain a non-overlapping packing of all modules which achieves some optimization objectives such as the area of the packing, the interconnection length and the congestion cost.

In this paper, we propose a new congestion model to estimate the congestion cost of a floorplan solution. Once the relative positions of the modules are determined, the pins could be placed temporarily to compute the interconnection length and congestion cost. Here we use the intersection-to-intersection method[4] to locate the pins and assume that nets will be routed over-the-cell in multi-bend shortest Manhattan distance. Due to the assumption of the routing path, it is obvious that all possible routing paths of one net could form a single point when two pins are at the same position, or a line when two pins are located vertically or horizontally, or otherwise a rectangular region including two pins exactly. In the later discussion we will only focus on the nets whose probable routing paths form a rectangular region and we call it the "routing range" of the net in this paper for convenience.

According to the relative positions of pins, the nets are divided into two types: *type I* if one of the pins is lower-left against the other one, and *type II* if one of the pins is upper-left against the other one. Besides we also define that for a net N_i, the pin p_1^i is on the other pin p_2^i's left (see figure 1).

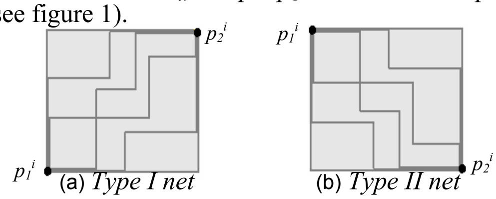

Figure 1. *Type I* and *type II* nets

3. Probabilistic Analysis Congestion Estimation

In this section we will review the congestion model proposed in [4] which use the concept of probabilistic analysis originally in [3]. Given a floorplan solution, first divide it into a 2-dimensional array with fixed-size grids. The routing range of each net may be covered by a set of grids. In figure 2(a) for a *type I* net the number of routes starting from p_1^i and p_2^i respectively to each grid is obtained. Therefore we make the following definition:

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Definition 1: Assume that the routing range of N_i is covered by $g_1^i \times g_2^i$ grids, and the coordinate of the grid in the most lower-left corner to be (0, 0). For $0 \le x < g_1^i$ and $0 \le y < g_2^i$, $Ta_i(x, y)$ and $Tb_i(x, y)$ indicate the number of possible monotonic routes starting from the grid of p_1^i and p_2^i respectively to the grid at (x, y), and otherwise, $Ta_i(x, y)$ and $Tb_i(x, y)$ are both 0. Note that when we assume the coordinate of the grid in the most lower-left corner to be (0, 0), the coordinates of p_1^i and p_2^i become (0, 0) and (g_1^i-1, g_2^i-1) for *type I* net respectively, and they become $(0, g_2^i-1)$ and $(g_1^i-1, 0)$ for *type II* net respectively.

p_2^i

1	5	15	35	70	126
1	4	10	20	35	56
1	3	6	10	15	21
1	2	3	4	5	6
1	1	1	1	1	1

p_1^i (a) $Ta_i(x, y)$

p_2^i

1	1	1	1	1	1
6	5	4	3	2	1
21	15	10	6	3	1
56	35	20	10	4	1
126	70	35	15	5	1

p_1^i (b) $Tb_i(x, y)$

Figure 2. The number of routes from pins to each grid

By *Definition 1*, we can calculate the number of routes for N_i passing through the grid at (x, y) by computing $Ta_i(x, y) \times Tb_i(x, y)$. For a *type I* net, the total number of routes is $Ta_i(g_1^i-1, g_2^i-1)$, so the probability for N_i passing through the grid at (x, y) is

$$\left(Ta_i(x,y) \times Tb_i(x,y)\right) \big/ Ta_i(g_1^{\,i}-1, g_2^{\,i}-1).$$

For a *type II* net, the total number of routes is $Ta_i(g_1^i-1, 0)$, so the probability for N_i passing through the grid at (x, y) is

$$\left(Ta_i(x,y) \times Tb_i(x,y)\right) \big/ Ta_i(g_1^{\,i}-1, 0).$$

$Ta_i(x, y)$ and $Tb_i(x, y)$ can be calculated by the following formula:

Formula 1: For $0 \le x < g_1^i$ and $0 \le y < g_2^i$,

(1) N_i is *type I*:

$$Ta_i(x, y) = \binom{x+y}{y} \text{ and}$$

$$Tb_i(x, y) = Ta_i(g_1^i-1-x, g_2^i-1-y) = \binom{g_1^{\,i}+g_2^{\,i}-2-(x+y)}{g_2^{\,i}-1-y}$$

(2) N_i is *type II*:

$$Ta_i(x, y) = \binom{x+(g_2^{\,i}-1-y)}{x} \text{ and}$$

$$Tb_i(x, y) = Ta_i(g_1^i-1-x, g_2^i-1-y) = \binom{(g_1^{\,i}-1-x)+y}{g_1^{\,i}-1-x}$$

The probability of N_i pass through the grid at (x, y) can be calculate by *Formula 2*.

Formula 2: For $0 \le x < g_1^i$ and $0 \le y < g_2^i$,

(1) N_i is *type I*: the probability for N_i passing through the grid at (x, y)

$$P_i(x,y) = \frac{\binom{x+y}{y} \times \binom{g_1^{\,i}+g_2^{\,i}-2-(x+y)}{g_2^{\,i}-1-y}}{\binom{g_1^{\,i}+g_2^{\,i}-2}{g_2^{\,i}-1}}$$

(2) N_i is *type II*: the probability for N_i passing through the grid at (x, y)

$$P_i(x,y) = \frac{\binom{x+(g_2^{\,i}-1-y)}{x} \times \binom{(g_1^{\,i}-1-x)+y}{g_1^{\,i}-1-x}}{\binom{g_1^{\,i}+g_2^{\,i}-2}{g_2^{\,i}-1}}$$

Note that when $0 > x$ or $x \ge g_1^i$ or $0 > y$ or $y \ge g_2^i$, $P_i(x, y)$ must be 0.

After processing all the nets, we can add up the probabilities for each net passing through one grid to be the estimated congestion cost of that grid. Larger the estimated cost of a grid is, more congested the grid might be. The congestion information at grid (x, y) is defined as

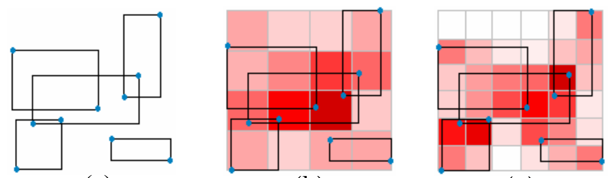
$$f(x,y) = \sum_{i=1}^{n} P_i(x,y).$$

Finally the average of the estimated cost of the top 10% most congested grids is used to represent the entire congestion cost of a floorplan solution.

4. Irregular-Grid Congestion Model

4.1 Motivations and Notions

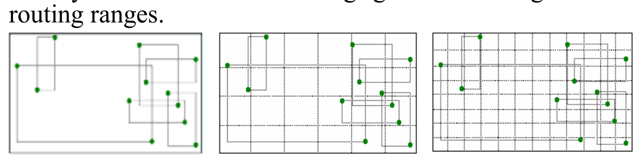
A good congestion model should be accurate enough to estimate the real congestion and also fast enough to be embedded into a floorplanner. The previous congestion model with fixed-size grid proposed in [4] has a serious trade-off between accuracy and efficiency, because the fixed size of grids affects both of them simultaneously. Figure 3(a) shows five routing regions for five nets. A chip which is divided into 4×4 (6×6) fixed-size grid is shown in figure 3(b) (3(c)). Cells with higher congestion are colored darker. This example shows the size of grid actually affect the estimation of congestion.



(a) (b) (c)

Figure 3. Congestion estimation with different grid sizes

The examples in figure 4 present the problem may be caused due to fixed cutting grid size. Figure 4(a) shows a floorplan solution and the routing ranges of six nets. Note that most of the nets are distributed on the right part of the whole plane, and it is supposed to be more congested there. In figure 4(b) and 4(c) the floorplan is divided into 6×4 and 12×8 grids respectively. In figure 4(b) the longest net on the right part of the plane is only covered by 6 grids and it is obvious the estimated result may not be reliable. On the other hand, the estimation must be more precise in figure 4(c) and surely the computing time is longer. However we observed that there are more than a half of grids only being passed through by one net which will never lead to congestion. It means there must be some time being consumed in these unnecessary region. This also motivates us to think about the wasted time on processing some negligible parts. It is seem reasonable that computing the congestion of every intersection of routing ranges is more meaningful than spending time on several fixed-size grids in one intersection of routing ranges. For this notion, we try to construct estimating grids according to the routing ranges.



(a) (b) (c)

Figure 4. Examples for cutting with different grid sizes

4.2 Irregular-Grid

Our model uses the routing ranges of the nets to divide the layout. Every routing range will create two horizontal and two vertical cutting-lines which are extended from four boundaries of the routing range. We named the partitioned graph “Irregular-Grid” and each partitioned irregular-size rectangle “IR-grid” to be distinguished from the fixed-size grid. Figure 5 is a floorplan and the corresponding Irregular-Grid consists 12 × 11 IR-grids. Every net will pass through several entire IR-grids because the pins must be right on the cutting-lines. The gray area shows a routing range and consists of 6 × 6 IR-grids.

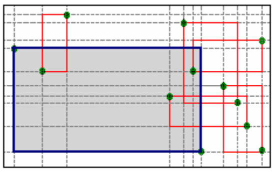


Figure 5. Irregular-Grid

4.3 Probability Estimation to an IR-grid

Just as the estimation method with fixed-size grids, we have to compute the probabilities for each net passing through IR-grids first. The summation of the probabilities for all nets crossing an IR-grid is regarded as the estimated congestion cost of it. Note that the estimated cost here can not be used directly to judge the solution, because the sizes of IR-grids are not the same. A smaller IR-grid will be more congested than a larger one theoretically when they have an equal estimated cost. Hence we determine the sum of the probabilities crossing an IR-grid divided by the area of it to be the congestion cost of every area unit in the IR-grid. Figure 6 shows a routing range of a *Type I* net which is divided into 6 × 6 fixed-size grids, and the *Ta* and *Tb* of every grid in figure 6(a) and 6(b) respectively. Assume that there is an IR-grid in the routing range involving 3 × 4 grids presented by a black frame in figure 6. We found that all the routes passing through the white grids in the IR-grid are involved into the routes passing through the gray grids, so we only need to compute the routes crossing each gray grid without duplicating. Therefore we derived the formulas as follows:

Formula 3: Assume that there exists an IR-grid I which covers from x_1^I to x_2^I in x-direction and from y_1^I to y_2^I in y-direction where $0 \le x_1^I < g_1^i$, $0 \le x_2^I < g_1^i$, $0 \le y_1^I < g_2^i$, $0 \le y_2^I < g_2^i$. That is, the IR-grid I can be described as a set

$$\text{IR}-\text{grid } I = \left\{(x,y) \mid x_1^I \le x \le x_2^I \text{ and } y_1^I \le x \le y_2^I\right\}.$$

(1) N_i is *type I*: probability P^I_i that a route connecting the net N_i and pass through IR-grid I is

$$\frac{\sum_{x=x_1^I}^{x_2^I}\left[Ta_i(x,y_2^I)\times Tb_i(x,y_2^I+1)\right]+\sum_{y=y_1^I}^{y_2^I}\left[Ta_i(x_2^I,y)\times Tb_i(x_2^I+1,y)\right]}{Ta_i(g_1^i-1,g_2^i-1)}$$

(2) N_i is *type II*: probability P^I_i that a route connecting the net N_i and pass through IR-grid I is

$$\frac{\sum_{x=x_1^I}^{x_2^I}\left[Ta_i(x,y_1^I)\times Tb_i(x,y_1^I-1)\right]+\sum_{y=y_1^I}^{y_2^I}\left[Ta_i(x_2^I,y)\times Tb_i(x_2^I+1,y)\right]}{Ta_i(g_1^i-1,0)}$$

The congestion information function F(I) at IR-grid I can be calculated by

$$\text{F}(I) = \sum\nolimits_{i=1}^{n} P_i^I .$$

Figure 6 shows a net with pins at (0, 0) and (6, 6). An IR-grid $I = \{(x, y) \mid 2 \le x \le 4,\ 2 \le y \le 5\}$. The number of routes connecting the pin passing through IR-grid I is 5×1 + 15×1 + 35×1 + 4×5 + 10×4 + 20×3 + 35×2 = 245 and the probability is 245/252.

1	6	21	56	126	252
1	5	15	35	70	126
1	4	10	20	35	56
1	3	6	10	15	21
1	2	3	4	5	6
1	1	1	1	1	1

(a)

1	1	1	1	1	1
6	5	4	3	2	1
21	15	10	6	3	1
56	35	20	10	4	1
126	70	35	15	5	1
252	126	56	21	6	1

(b)

Figure 6. Example for a net passing through an IR-grid

The new irregular-grid congestion estimation model described here can be easily embedded into a floorplanner to estimate the congestion of floorplans. In next section, we will derive some accurate and efficient approximating formulas for Formula 3. Consequently, the advantages of our new irregular-grid model will become clear and will be described in Section 4.7.

4.4 Approximating formulas

It is obvious that *Formula 3* still exhibits the correlation between the grid size and the time complexity. Hence we tried to derive formulas to approximate to *Formula 3* and simplify the computation to constant time. For a *type I* net N_i, we could obtain the probability for N_i passing through an IR-grid I by calculating

$$\frac{\sum_{x=x_1^I}^{x_2^I}\left[Ta_i(x,y_2^I)\times Tb_i(x,y_2^I+1)\right]+\sum_{y=y_1^I}^{y_2^I}\left[Ta_i(x_2^I,y)\times Tb_i(x_2^I+1,y)\right]}{Ta_i(g_1^i-1,g_2^i-1)}$$

It could be rewritten to

$$\sum_{x=x_1^I}^{x_2^I}\left[\frac{Ta_i(x,y_2^I)\times Tb_i(x,y_2^I+1)}{Ta_i(g_1^i-1,g_2^i-1)}\right]+\sum_{y=y_1^I}^{y_2^I}\left[\frac{Ta_i(x_2^I,y)\times Tb_i(x_2^I+1,y)}{Ta_i(g_1^i-1,g_2^i-1)}\right]$$

And then we will discuss the two functions

$$\frac{Ta_i(x,y_2^I)\times Tb_i(x,y_2^I+1)}{Ta_i(g_1^i-1,g_2^i-1)} \quad \text{……}\textit{Function (1)}$$

and

$$\frac{Ta_i(x_2^I,y)\times Tb_i(x_2^I+1,y)}{Ta_i(g_1^i-1,g_2^i-1)} \quad \text{……}\textit{Function (2)}$$

separately.

Substituting the corresponding values in to *Function (1)*, *Function (1)* can be written as

$$\frac{\binom{x+y_2^I}{x}\times\binom{g_1^i+g_2^i-x-y_2^I-3}{g_1^i-x-1}}{\binom{g_1^i+g_2^i-2}{g_1^i-1}} = \frac{g_2^i-1}{g_1^i+g_2^i-2}\times\frac{\binom{x+y_2^I}{x}\times\binom{g_1^i+g_2^i-x-y_2^I-3}{g_1^i-x-1}}{\binom{g_1^i+g_2^i-3}{g_1^i-1}}$$

Observe that

$$\frac{\binom{x+y_2^I}{x}\times\binom{g_1^i+g_2^i-x-y_2^I-3}{g_1^i-x-1}}{\binom{g_1^i+g_2^i-3}{g_1^i-1}} = \frac{\binom{x+y_2^I}{x}\times\binom{(g_1^i+g_2^i-3)-(x+y_2^I)}{(g_1^i-1)-x}}{\binom{(g_1^i+g_2^i-3)}{(g_1^i-1)}} = \frac{\binom{Q}{x}\times\binom{R-Q}{r-x}}{\binom{R}{r}}$$

$$= h(x,r,R,Q),$$

where $Q=x+y_2^I$, $R=g_1^i+g_2^i-3$ and $r=g_1^i-1$. Note that Q involves the variable x, $h(x,r,R,Q)$ is *not* a real hypergeometric distribution[2], but it is a hypergeometry-like function. It has been proved that binomial distribution may approximate to hypergeometric distribution quite precisely and moreover normal distribution could also approximate to binomial distribution while assuming the function to be continuous instead of discrete. Although Q in $h(x,r,R,Q)$ involves the variable x, we can still use the similar technique used to approximate a hypergeometric distribution to a normal distribution to approximate $h(x,r,R,Q)$ to a normal-distribution-like function

$$\frac{1}{\sqrt{2\pi}\sigma_x}\exp\left[\frac{-(x-\mu_x)^2}{2\sigma_x^2}\right]$$

where

$$\mu_x=(g_1^i-1)\times\frac{x+y_2^I}{g_1^i+g_2^i-3}$$

$$\sigma_x^2=\left(\frac{g_2^i-2}{g_1^i+g_2^i-4}\right)\times(g_1^i-1)\times\frac{x+y_2^I}{g_1^i+g_2^i-3}\times\left(1-\frac{x+y_2^I}{g_1^i+g_2^i-3}\right)$$

provided that μ_x is *not* too near either 0 or 1[2].

Function (1) becomes

$$\frac{g_2^i-1}{g_1^i+g_2^i-2}\times\frac{1}{\sqrt{2\pi}\sigma_x}\exp\left[\frac{-(x-\mu_x)^2}{2\sigma_x^2}\right]$$

Function (2) could be approximated in the same way.

Since the functions have been regarded as continuous, the summation functions could be substituted for integral functions. Therefore finally the approximating formulas are derived as follows:

Theorem 1: Assume that there exists an IR-grid I which covers from x_1^I to x_2^I in x-direction and from y_1^I to y_2^I in y-direction in the grids where $0 \le x_1^I < g_1^i$, $0 \le x_2^I < g_1^i$, $0 \le y_1^I < g_2^i$, $0 \le y_2^I < g_2^i$.

(1) N_i is *type I*: the probability P_i^I for N_i passing through I is

$$P_i^I \approx \int_{x_1^I}^{x_2^I}\left[\frac{g_2^i-1}{g_1^i+g_2^i-2}\times\frac{1}{\sqrt{2\pi}\sigma_1}\exp\left[\frac{-(x-\mu_1)^2}{2\sigma_1^2}\right]\right]dx$$

$$+\int_{y_1^I}^{y_2^I}\left[\frac{g_1^i-1}{g_1^i+g_2^i-2}\times\frac{1}{\sqrt{2\pi}\sigma_2}\exp\left[\frac{-(y-\mu_2)^2}{2\sigma_2^2}\right]\right]dy$$

Where

$$\mu_1=(g_1^i-1)\times\frac{x+y_2^I}{g_1^i+g_2^i-3},\quad \mu_2=(g_2^i-1)\times\frac{x_2^I+y}{g_1^i+g_2^i-3}$$

$$\sigma_1^2=\left(\frac{g_2^i-2}{g_1^i+g_2^i-4}\right)\times(g_1^i-1)\times\frac{x+y_2^I}{g_1^i+g_2^i-3}\times\left(1-\frac{x+y_2^I}{g_1^i+g_2^i-3}\right)$$

$$\sigma_2^2=\left(\frac{g_1^i-2}{g_1^i+g_2^i-4}\right)\times(g_2^i-1)\times\frac{x_2^I+y}{g_1^i+g_2^i-3}\times\left(1-\frac{x_2^I+y}{g_1^i+g_2^i-3}\right).$$

(2) N_i is *type II*: the probability P_i^I for N_i passing through I can be derived in the similar way.

The definite integral in the above equation can be easily computed by Simpson's rule of integration in constant time. Precision of the above approximating formulas is discussed in the next section.

4.5 Precision Analysis and Calculation Rule Modification

Although the approximating formulas are generally very effective and precise, there still exists a little failings in some cases. Due to the inherent weakness of the transformations between distributions, our approximating formulas will result in some inaccuracy and even errors. Take *Function (1)* for example. When $(x+y_2^I)/(g_1^i+g_2^i-3)$ equals to 0, 1, or greater than 1, in these cases μ_x is too near either 0 or 1. *Function (1)* will return an error value. The cases are discussed separately:

(1) Only when $x = 0$ and $y_2^I = 0$, $(x+y_2^I)/(g_1^i+g_2^i-3) = 0$.
(2) Only when $x = g_1^i-2$ and $y_2^I = g_2^i-1$, or $x = g_1^i-1$ and $y_2^I = g_2^i-2$, $(x+y_2^I)/(g_1^i+g_2^i-3) = 1$.
(3) Only when $x = g_1^i-1$ and $y_2^I = g_2^i-1$, $(x+y_2^I)/(g_1^i+g_2^i-3) > 1$.

Similarly the same condition can be derived for *Function (2)*. Accordingly for a *type I* net incorrect approximation will be caused at grid (0, 0), (g_1^i-2, g_2^i-1), (g_1^i-1, g_2^i-2), and (g_1^i-1, g_2^i-1) in the routing range (as the gray grids shown in figure 7).

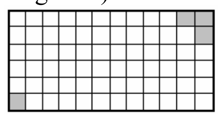


Figure 7. Gray grids may cause incorrect approximation

Because of the approximating errors, the algorithm has to be modified to avoid computing the error-making grids. Fortunately, we discovered that these grids are always exactly near two pins of a net (see figure 7). And we have already known that the probability for a net passing through IR-grids which cover any pin is always 1. Therefore we try to embrace the error-making grids into one IR-grid and then we can skip the computation to assign it 1 directly.

We take a real case for example. Assume there is a *type I* net which is divided into 31×21 grids. If an IR-grid is in the routing range of the net as shown in figure 8(a), the two compared curves of the real values and the approximating values for $x = 10, 11, \ldots, 20$ and $y = 15$ (the top y-coordinate of the IR-grid) of *Function (1)*) are drawn in figure 8(b). It is obvious that the approximation is extremely accurate. If an IR-grid is as shown in figure 8(c), *Function (1)* will make a mistake at grid (30, 19). Therefore the approximating curve in figure 8(d) shows no value when $x = 30$. Besides, the deviation of approximation is generally less than 0.05 and our derived formulas are applicable to replace the original complex formulas.

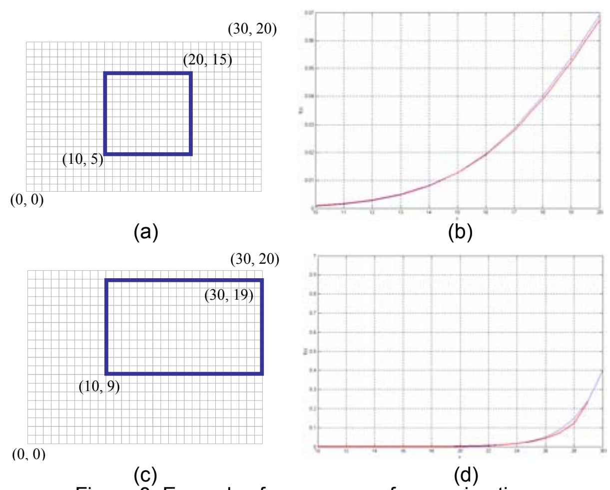


Figure 8. Examples for accuracy of approximation

4.6 Algorithm

The Irregular-Grid congestion model can be embedded into any general floorplanners to estimate the probable congestion of every intermediate floorplan solution. And the estimated cost could be regarded as one of the criterions to judge a floorplan solution. Therefore given a floorplan solution, the estimating process is stated as follows:

Algorithm Congestion Information Computation

Input : A floorplan with net information

Output : Congestion information of the floorplan

begin

1 Determine the dividing lines determinted by the routing ranges of nets;
2 Remove any two lines whose interval is smaller than the double of the width/length of a grid and modify the corresponding routing ranges;
3 For each net
  3.1 Assign 1 to the passing probabilities of the IR-grids which cover pins;
  3.2 Compute the passing probabilities of the other IR-grids which are in the routing range by approximating formulas;
  3.3 Add the passing probability of each IR-grid to its own record of the congestion cost;
4 For each IR-grid
  4.1 Compute the congestion information;
5 Return the average of the congestion cost of the top 10% most congested area units;

end

4.7 Advantages

The Irregular-Grid congestion model provides a accurate and effective method to estimate the congestion in floorplanning. Since the information of routing is used to divide the estimated sections, it has some additional advantages as below: (1) It provides a reasonable and generalized partitioning basis to various circuits while evaluating congestion. (2) It decreases the high dependency between the estimating accuracy and the number of estimating grids. (3) Instead of computing the probably less congested portions, spending more time on the probably more congested portions helps improving the accuracy and saving the run time.

We derive a powerful approximating formula to replace the complex compute of probabilities and the time complexity is only constant time. The total time complexity of the algorithm proposed in [4] is $O(n \times G_1 \times G_2)$, where n is the number of 2-pin nets, and $G_1 \times G_2$ is the number of grids. The total time complexity of our approach is also $O(n \times G_1 \times G_2)$, where $G_1 \times G_2$ is changed to the number of IR-grids. Due to the relation between the numbers of nets and IR-grids, the time complexity can be rewritten to $O(n^3)$. However in the real case, the number of IR-grids is much fewer than n^2 because a lot of cutting-lines will duplicate.

5. Experimental Results

The test circuits are five MCNC benchmarks. All the experiments were implemented on Intel 2. 4GHz processor with 256MB memory. Three experiments are designed to test our new congestion model. In these experiments, the floorplanner we used is based on simulated annealing algorithm with normalized Polish expression[7]. The optimal objectives could be the minimization of the area, the interconnection length and the estimated congestion cost. To compute the interconnection-related objectives, we decompose the multi-pin nets into several 2-pin nets by minimum spanning tree. As in [4], the intersection-to-intersection method is used to distribute the I/O pins into grids appropriately. The total wire length can be then computed. The congestion cost for a floorplan is calculated as the sum of rules of congestion information functions for the top 10% most congested IR-grids. The cost function used in the following experiments have the from $\alpha \times Area + \beta \times Wirelength + \gamma \times Congestion$. Every test case is performed 20 times using different random number generator seeds, and the average and the best results measured *according the cost function* used in the experiment, are reported in the following tables.

In order to verify the correctness of estimation, a fair judging method is needed. We use the congestion model proposed in [4] with very small fixed-size grid ($10 \times 10\ \mu m^2$ in experiments), and called it the "*judging model*" for convenience. In the following experiments, we embed our IR-grids model in a floorplanner to get a solution (a floorplan), and then use the "*judging model*" to compute the congestion information for *the* solution so that we can compare our solutions with solutions obtained by other floorplanner using fixed-size grid model.

5.1 Experiment 1

In this experiment we test two floorplanners: one only optimizes the area and the interconnection length, and the other additionally optimizes the congestion cost estimated by our new model. We use the judging model to evaluate the congestion of the two floorplan solutions generated by the above floorplanners. The decrease in the congestion could verify that our new model can be embedded into a floorplanner and reduce the congestion of the floorplan solution effectively.

Table 1 shows the area and the wire length of the average and the best results of the first floorplanner. Table 2 additionally shows the congestion cost estimated by our new model (*IR-grid cgt cost*) of the results of the second floorplanner. Both results are also tested by the judging model (*judging cgt cost*). The comparison between Table 1 and 2 is shown in Table 3. We observe that the congestion falls down substantially with a little penalty in the area and the wire length. This phenomenon is reasonable for several objectives existing simultaneously, and our Irregular-Grid model can be used to help the floorplanner obtain a solution with less congestion.

5.2 Experiment 2

In this experiment we test the correctness of the Irregular-Grid model to make sure the estimated results approach to the real congestion situation. In this experiment the floorplanner only optimize the congestion cost based on our new model. In the process of floorplanning we extract the intermediate solution at each temperature-dropping step, which is also a locally-optimized solution, and apply two judging models with different grid sizes to it. In figure 9 three curves show these three values in obtaining order 1 to 20 (test circuit *ami33*). Curve *A* is composed of the congestion costs computed by our new model with $30 \times 30\ \mu m^2$ grid size. Curve *B* and *C* are composed of the congestion costs computed by the judging models with 10×10 and $50 \times 50\ \mu m^2$ grid sizes respectively. Notice that we do 100 multiplies the values on curve *A* and 2.5 multiplies the values on curve *B* for adjusting the ranges of these three values to be near. We can observe that the slopes of curve *A* and *B* are more similar than the slopes of curve *A* and *C*. This indicates that the estimation of our model is as accurate as the fixed-size grid model with small grid size and can reflect the real congestion situation in floorplanning.

5.3 Experiment 3

In this experiment we compare the performance of Irregular-Grid model with the fixed-size grid model to verify the accuracy and efficiency of our model. We use two floorplanners which both optimize the congestion cost only using our new model and fixed-size grid model respectively. Table 4 and 5 show the grid size, the number of grids, congestion cost, and run time of the average and best solutions of two floorplanners (test circuit *ami33*). Besides, a judging model is also used to estimate the congestion of each floorplan solution (*judging cgt cost*). We can observe that the run time using our new model is about 2.3 times less than using the fixed-size grid model with grid size 100 × 100 μm^2, however the judging congestion cost reduces 8.79% in average. And comparing with the fixed-size grid model with grid size 50 × 50 μm^2, the run time is 3.5 times less and the judging congestion cost reduces 4.59%. Therefore we prove that our new model could safe time to improve the estimating accuracy and certainly achieve our theoretical benefit.

6. Conclusion

We propose a concept of irregular-size grid to build up a new congestion model. Due to the effective approximating probability formulas we derived, our new model could estimate congestion of a floorplan more accurately in less run time. Besides, our model provides a reasonable basis to partition the estimating region. Finally three complete testing experiments are processed and the experimental results show the ability of our model to estimate congestion more accurately and efficiently.

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Table 1. Results with fixed-size grid model

circuit	average results				best results			
	area (mm^2)	wire length (μm)	time (*sec*)	judging cgt cost	area (mm^2)	wire length (μm)	time (*sec*)	judging cgt cost
apte	48.52	190749	36.7	0.314989	47.63	196240	38	0.20913
xerox	22.22	136281	48.9	0.140384	21.25	93361	47	0.080556
hp	9.65	64784	24	0.176407	9.33	48066	25	0.152014
ami33	1.27	82366	196	0.5029	1.22	81483	200	0.470891
ami49	42.75	1067681	479.3	0.191047	42.46	1046063	487	0.205271

Table 3. Comparison between Table 1 and 2

circuit	Improvement of average results			Improvement of best results		
	area (%)	wire length (%)	judging cgt (%)	area (%)	wire length (%)	judging cgt (%)
apte	0.577	-1.566	12.128	-0.59	12.3	10.93
xerox	-2.33	-4.68	20	7.1	-27.7	7.9
hp	-5.6	4.88	9.46	-8.9	-14.4	11.32
ami33	-1.57	3.5	5.59	-3.28	8.26	7.3
ami49	-0.09	-3.46	1.96	-0.42	0.02	18.26

Table 2. Results with Irregular-Grid model

circuit	grid size (μm^2)	average results					best results				
		area (mm^2)	wire length (μm)	IR-grid cgt cost (×1000)	time (sec)	judging cgt cost	area (mm^2)	wire length (μm)	IR-grid cgt cost (×1000)	time (sec)	judging cgt cost
apte	60×60	48.24	193736.9	0.1531	198.9	0.276787	47.91	172163	0.1296	191	0.186267
xerox	30×30	22.75	142668.2	0.209	203.4	0.1123039	19.74	119235.8	0.162	211	0.0741933
hp	30×30	10.19	61624.3	0.4054	106.3	0.1597123	10.17	54987.5	0.3438	110	0.134803
ami33	30×30	1.29	79482.3	5.241	296.5	0.4748	1.26	74750.3	5.153	307	0.4365
ami49	30×30	42.79	1104683.9	0.54383	1254.1	0.187311	42.64	1045836.8	0.515	1161	0.167791

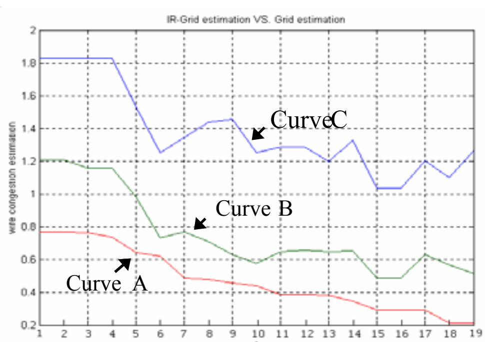

Figure 9. Comparison between the fixed-size grid model and Irregular-Grid model (*ami33*)

Table 4. Results with Irregular-Grid model (congestion optimization only)

grid size (μm^2)	average results				best results			
	# of IR-grid	IR-grid cgt cost (×100)	Time (*sec*)	judging cgt cost	# of IR-grid	IR-grid cgt cost (×100)	time (*sec*)	judging cgt cost
30×30	589	0.2358	27.7	0.21239	25×25	0.2328	31	0.163903

Table 5. Results with fixed-size grid model (congestion optimization only)

grid size (μm^2)	average results				best results			
	# of grid	grid cgt cost	Time (*sec*)	judging cgt cost	# of grid	grid cgt cost	time (*sec*)	judging cgt cost
100×100	557	0.528656	63.6	0.231073	23×33	0.518196	67	0.166933
50×50	2215	0.356049	96	0.22215	42×60	0.30192	96	0.167464