AN INTERCONNECTION LENGTH ESTIMATION FOR MULTI-POINT NETS

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ABSTRACT

The increasing system complexity imposes high demands on computer aided design (CAD) tools for system synthesis. Especially the layout (placement and routing) of a design has become a problem hard to solve. To find a 'good' layout, CAD tools need accurate estimators to predict area requirements, interconnection lengths, power dissipation, etc. In this paper we address the estimation of interconnection lengths. Previous work on interconnection length estimations is primarily based on a technique introduced by Donath [1] which has been improved by Stroobandt et al [2]. However, no previous work on estimating design properties (e.g. interconnection lengths) takes multi-point nets into account. All nets are assumed to be 2-point nets. In this paper, we will estimate the average interconnection length for multi-point nets. This estimation is based on our recent research on the behaviour of multi-point nets during the partitioning process and on the distribution of nets over their net degree [3].

Keywords: Multi-point Nets, Net Degree Distribution, Interconnection Length Estimation.

1 INTRODUCTION

The production of VLSI and ULSI computer chips requires the layout (placement and routing) of the chip design on a carrier. In the early days of chip design, manually designing a chip was still feasible. Nowadays, computer aided design (CAD) tools are indispensable to cope with the complexity and the limited time resources.

For the high demands put on system performances these days, CAD tools often lack enough flexibility. Especially for the placement and routing phases extremely high demands are set and accurate predictions of system performances are needed to limit the search in the vast solution space. CAD tools therefore use estimator tools [1,2,4], usually based on partitioning methodologies [5].

The main design parameters that have to be estimated are the interconnection length within the placed design, area occupancy, clock frequency, power dissipation, and (especially for FPGA's) channel densities. The estimation can be performed before the design is actually placed and then used to obtain better layouts [2]. The estimates can also be used for gaining a more fundamental insight in the placement of designs on different carriers. A lot of research performed by Van Marck and Stroobandt is aimed at evaluating three-dimensional architectures where optical channels are used for the third dimension interconnections [4,6]. The possibilities of such architectures can be explored without the need to actually produce the systems.

Previous work on interconnection length estimates is primarily based on a technique introduced by Donath [1] which has been improved by Stroobandt et al [2]. However, none of the currently developed techniques takes multi-point nets into account in general (although, for specific nets, a Steiner tree approximation is sometimes used). Yet, in [3] we showed that net degree distributions can vary a lot over different designs and this has a profound impact on the interconnection length. The goal of this paper is to estimate the average interconnection length for multi-point nets. The estimation is based on previous work on characterizing the behaviour of multi-point nets during the partitioning process and on the distribution of nets over their net degree [3].

2 ESTIMATION OF THE AVERAGE INTERCONNECTION LENGTH

Donath [1] observed that the best estimates of interconnection lengths can be found by using a hierarchical model of the design and the architecture where the design should be implemented in. The model for the design is based on Rent's rule [7] which is a relationship between the number of elementary blocks B in a module of a partitioned design, and the number of the module's external connections (pins) P:

$$P = T_b\, B^r, \tag{1}$$

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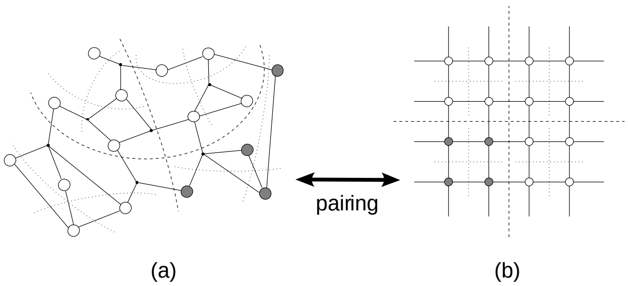

Figure 1. HIERARCHICAL PARTITIONING OF THE DESIGN (a) AND THE ARCHITECTURE (b)

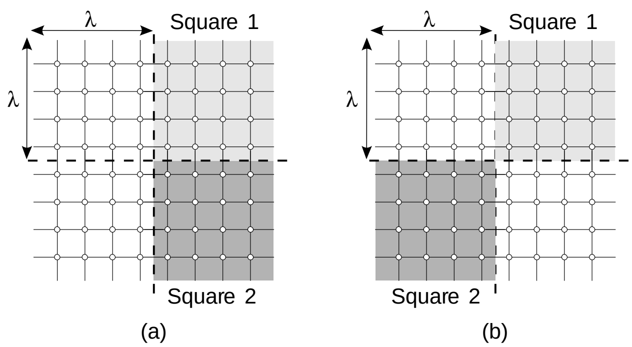

Figure 2. AN A-COMBINATION (a) OF ADJACENT SQUARES AND A D-COMBINATION (b) OF DIAGONALLY OPPOSED SQUARES.

where T_b is the average number of terminals per logic block, and r is called the *Rent exponent*. The architecture is modelled as a square Manhattan grid where the grid-points correspond to places where the logic blocks of the design can be placed and the grid-lines correspond to the channels where the interconnections between logic blocks can be routed. The placement process is modelled as a hierarchical partitioning of both the design and the architecture. At each hierarchical level, each subdesign is paired with a subsquare in the architecture (figure 1).

At every hierarchical level, the average length can be computed between points of different subarchitectures. These can be adjacent to each other (and are then called A-combinations) or they can be diagonally opposed (D-combinations) (figure 2). If one assumes that every point of square 1 can be connected to every point of square 2 with equal probability then it can be proven that, for point-to-point interconnections, the average length within an A-combination with squares of side λ is given by $4/3\,\lambda - 1/(3\,\lambda)$ and the average length of a D-combination is given by $2\,\lambda$ [1,2].

In this paper we study the average length of multi-point nets. We will say that a multi-point net belongs to a certain hierarchical level k if it has points in at least two of the subsquares at level k and if it is fully contained in one subsquare of level $k+1$ (which is the level with squares of size $2\,\lambda$). We shall first compute what we call the *pairs length* l_p of a multi-point net [8]. It is defined as the total length between all pairs of terminals of the multi-point net. We assume that all terminals of the n-point net are situated in two of the four subsquares at hierarchical level k. This assumption is based on the knowledge that the partitioning should be done in such a way that the total number of pins is minimized. A partitioning program will therefore (at each level) prefer to cut the nets only once. The average pairs length (for A- as well as for D-combinations) can then be calculated by stating that one terminal should be in square 1, one terminal in square 2 and the other terminals can be chosen randomly in one of both squares. The average pairs length can then be seen to be

$$\frac{2\,\left(2\,\lambda^2+1\right)+3\,n\,(n-1)\,\left(2\,\lambda^2-1\right)}{12\,\lambda} \tag{2}$$

for an A-combination and

$$\frac{2\,\left(2\,\lambda^2+1\right)+n\,(n-1)\,\left(4\,\lambda^2-1\right)}{6\,\lambda} \tag{3}$$

for a D-combination. Because there are four possible A-combinations and only two D-combinations in a square grid, the total average pairs length is given by

$$\frac{2\,\left(2\,\lambda^2+1\right)+n\,(n-1)\,\left(5\,\lambda^2-2\right)}{9\,\lambda} \tag{4}$$

One can convince oneself of the plausibility of this equation by substituting n by 2. This results in the average length $14/9\,\lambda - 2/(9\,\lambda)$ which is the known solution for point-to-point connections [1,2].

The Steiner length of the n-point net can then be approximated based on the pairs length. This approximation is presented in [8] and is given by

$$\frac{3\,l_p}{n^{3/2}}. \tag{5}$$

It has been proven to be an improvement over existing approximations.

In [3] we showed that the *net degree distribution* $f_k(n)$, the distribution of nets over their net degree (number of terminals) n, follows a power law

$$f_k\,(n) = a\,(k)\;n^b, \tag{6}$$

where $b < 0$ and where $a(k)$ depends on the hierarchical level and can be computed using Rent's rule (equation 1). From this equation the number of n-point nets at each level k can be calculated.

The weighted average length for an n-point net over all levels k can then be found by combining equations 4, 5, and 6. This results in a new interconnection length estimate which relaxes the overestimation found with Donath's estimation technique [1].

Name	G	N	r	$\bar{l}_m$	$\bar{l}_D$	$\bar{l}_e$
c499	202	243	0.55	3.010	3.212	3.177
c880	383	443	0.57	3.031	3.689	2.764
c1355	546	587	0.50	2.788	3.554	2.804
c1908	880	913	0.52	2.744	3.910	2.866
c2670	1193	1350	0.57	2.927	4.476	2.817
c499nr	202	243	0.60	3.225	3.393	3.158
c1355nr	546	587	0.50	2.782	3.554	2.786
c1908nr	878	911	0.51	2.711	3.845	2.894
c2670nr	961	1118	0.59	2.968	4.475	2.483
s208.1	112	122	0.39	2.423	2.523	1.946
s298	133	136	0.42	2.533	2.649	2.654
s344	175	184	0.34	2.291	2.554	2.046
s349	176	185	0.38	2.377	2.651	2.046
s382	179	182	0.34	2.316	2.561	2.520
s386	165	172	0.57	3.162	3.160	3.713
s400	185	189	0.35	2.342	2.594	2.551
s420.1	234	252	0.38	2.402	2.743	2.090
s444	202	205	0.35	2.340	2.619	2.546
s510	217	236	0.66	3.406	3.685	4.037
s526	214	217	0.48	2.774	3.008	3.188
s641	398	433	0.52	2.534	3.471	1.883
s713	412	447	0.46	2.483	3.224	1.941
s820	294	312	0.57	3.307	3.518	5.229
s832	292	310	0.58	3.392	3.557	5.338
s838.1	478	512	0.38	2.400	2.964	2.182
s953	424	440	0.68	3.317	4.394	4.372
s1196	547	561	0.64	3.257	4.371	4.371
s1238	526	540	0.63	3.349	4.270	4.886
s1423	731	748	0.38	2.394	3.089	2.552
s1488	659	667	0.62	3.391	4.394	5.755
s1494	653	661	0.61	3.362	4.316	5.819

Table 1. THE NEW INTERCONNECTION LENGTH ESTIMATES COMPARED TO DONATH'S ESTIMATES FOR THE ISCAS BENCHMARK DESIGNS.

3 RESULTS

A comparison between the new estimates and Donath's estimates can be found in table 1 for the ISCAS benchmark set. The number of gates G, number of nets N, and the Rent exponent r are shown in the first columns. The new average length estimate is denoted by $\bar{l}_m$, Donath's average length by $\bar{l}_D$, and the experimentally obtained value by $\bar{l}_e$. One can see that our new estimates are almost always lower than Donath's, which are known to be an overestimation [1,2]. We also experimentally obtained average interconnection lengths by using a placement and routing program written at our department. It is based on Simulated Annealing. A comparison between the theoretical and the experimental values learns that our new estimates are more closely related to the experiments than Donath's (see table 1). On average, we underestimate the experimental values by 3.83% while Donath overestimates the experimental values by 15.25%. We should also keep in mind that the experimental placement is not optimal. The best placement and routing algorithm would thus result in even lower average lengths, which makes our results even better. Table 1 shows that taking multi-point nets into account results in more accurate interconnection length estimates.

4 CONCLUSION

Taking multi-point nets into account adds to the accuracy of interconnection length estimations for computer designs. Previous interconnection length estimates (based on Donath's technique [1]) do not take the net degree distribution into account. In [3] we showed that the net degree distribution can vary a lot, even for designs with the same Rent exponent. Since this will have a profound impact on the interconnection lengths within a placed design, we should take these variations into account. In this paper we provided a way to include the net degree information into the average interconnection length estimations. Further research should be carried out to improve the accuracy of the estimates. Possible extensions are to be found in the inclusion of information on the optimal placement behaviour [2] and on even more accurate estimates of the number of n-point nets at every hierarchical level in the placement process.

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