Research on Characteristic Parameters of Integrated Circuit

Zhangjin Ding \(^{1,a}\), Xiaoming Chen \(^{2,b}\)

\(^{1}\)Zhejiang University Hangzhou, Zhejiang, China
\(^{2}\)Harbin University of Science and Technology Harbin, Heilongjiang, China

\(^{a}\)zding1999@stu.suda.edu.cn
\(^{b}\)hrbustxm@163.com

Abstract—In order to study the complex network characteristics of integrated circuits, this paper studies the importance of different characteristic parameters in characterizing the complex network characteristics of integrated circuits by comparing the correlation between characteristic parameter changes and circuit changes. Through the experiments, the important parameters of characteristic parameters in the characterization of integrated circuits are obtained, which is helpful for the design and optimization of very large scale integration (VLSI).

1. CHARACTERISTIC PARAMETERS OF COMPLEX NETWORK

1.1. Network average
The degree \(k_i\) of node \(i\) is the number of other nodes connected to node \(i\). The average degree of the network is the average value of the degrees of \(N\) nodes in the network, which can be expressed as:

\[
\langle k \rangle = \frac{1}{N} \sum_{i=1}^{N} k_i
\]

1.2. Network density
Network density can be used to describe the density of connected edges between nodes in the network. It is defined as the ratio of the actual number of edges in the network to the upper limit of the number of edges that can be accommodated. It can be expressed as

\[
D = \frac{2M}{N(N-1)}
\]

Where, \(M\) is the actual number of connection edges in the network; \(N\) is the total number of network nodes. The value range of network density is \([0,1]\).

1.3. Average agglomeration coefficient
The clustering coefficient \(C_i\) refers to the probability that two nodes connected with node \(i\) are also connected with each other in the network. It represents the degree of clustering of nodes in the network. If a node \(i\) and a node \(k_i\) may have at most \(k_i(k_i-1)/2\) edges connected, and the actual number of edges is \(M_i\), the aggregation coefficient of node \(i\) can be expressed as:
The average clustering coefficient of the network is obtained by averaging the N nodes of the whole network

\[ C = \frac{1}{N} \sum_{i=1}^{N} C_i \]  

(4)

1.4. Average shortest path

The shortest path between two nodes i and j in the network is the path with the least number of sides, while the average shortest path L of the network is defined as the average value of the shortest distance between all node pairs, and the calculation formula is:

\[ L = \frac{1}{N^2} \sum_{i=1}^{N} \sum_{j=1}^{N} d_{ij} \]  

(5)

where N is the number of nodes in the network. For simple undirected graphs, dij=dji, and dii=0, formula (5) can be simplified as

\[ L = \frac{2}{N(N-1)} \sum_{i=1}^{N} \sum_{j=i+1}^{N} d_{ij} \]  

(6)

The average shortest path represents the average degree of separation between nodes in the network, that is, how small the network is.

2. INTRODUCTION

Integrated circuit (IC) has developed to the VLSI (very large scale integration) level. The degree of integration is further improved. The high complexity makes the physical design of integrated circuit increasingly difficult. In the absence of circuit electrical data, how to accurately identify and optimize the physical topology of integrated circuit is a new problem. As a new subject, complex network is a subject to explain the existing network phenomenon and its complexity. Because complexity is closely related to the structure and characteristics of the network, people attach great importance to the cross research of complexity and network. Nowadays, complex network has become a popular tool for network research and has been applied in various fields [1-2].

In this paper, the IBM-HB+Benchmark Suites benchmark circuit is used as the experimental circuit. Aiming at the high complexity of integrated circuit, by comparing the Pearson correlation coefficient between the change of characteristic parameters of complex network and the change of circuit, the average degree <K>, network density D, average clustering coefficient C and average shortest path L are analyzed to study the importance and weight of each characteristic parameter in the physical design of IC [3-6].

3. THE IMPORTANCE OF CHARACTERISTIC PARAMETERS IN CHARACTERIZING THE COMPLEX NETWORK CHARACTERISTICS OF INTEGRATED CIRCUITS

3.1. Basic ideas

With the development of IC integration, new problems have been brought forward in the integrated circuit identification, design and optimization. It has been proved that the complex network method has unique advantages in the efficient identification and characterization of IC physical design. Several different characteristic parameters of complex network can describe a certain characteristic of circuit network, but the importance of each characteristic parameter in characterizing integrated circuit is always ignored.
In order to explore the influence of different characteristic parameters on IC characterization and further study the complex network characteristics of IC, this paper proposes a method to compare the change rate. We make some changes to the circuit, get the characteristic parameters of the circuit after the changes. We compare the characteristics of the changes of the characteristic parameters with the changes of the circuit, study the closeness of the relationship between the characteristic parameters and the physical topology of the integrated circuit, that is, the importance of different characteristic parameters in the characterization of the integrated circuit, and get their weights. It provides ideas and methods for the future cross research of integrated circuit and complex network.

3.2. Importance calculation of characteristic parameters

The basic module in the reference circuit is regarded as a node, the wires between the modules are regarded as edges, and the experimental circuit abstracted into a complex network meets the small world characteristics. Therefore, the experimental circuit can be studied with the theory of complex network.

Input: integrated circuit complex network $G \{N, M\}$, network $G$ has $n$ nodes and $m$ edges.
Output: changed circuit $G'\{N', M'\}$, network $G'$ has $n'$ nodes and $M'$ edges.
Input: change rate of each characteristic parameter.
Output: the weight of each characteristic parameter in the characterization integrated circuit.

The specific steps are described as follows:

1) Change the circuit. Three methods are used to change the circuit:
   a) Randomly delete 5%, 10%, 15%, 20%, 25% and 30% modules in the circuit;
   b) Randomly delete 5%, 10%, 15%, 20%, 25%, 30% of the inter module connections in the circuit;
   c) Randomly reconnect 5%, 10%, 15%, 20%, 25%, 30% of the inter module connections in the circuit.

2) Calculate the change rate of characteristic parameters. Calculate four characteristic parameters of the circuit after each change: average degree $<K>$, network density $D$, average clustering coefficient $C$, average shortest path $L$, and calculate their change rate

$$\frac{<K>'-<K>}{<K>}\times100\%
\frac{D'-D}{D}\times100\%
\frac{C'-C}{C}\times100\%
\frac{L'-L}{L}\times100\%$$

(7)

The average change rate of seventeen circuits is calculated.

3) Find the correlation between the change of characteristic parameters and the change of circuit. The hypothesis of the change rate of four characteristic parameters obtained in one experiment is $k_1-k_6 (<K>), d_1-d_6 (D), C_1-C_6(C), l_1-l_6(L)$, and the Pearson correlation coefficient between each characteristic parameter and the change rate of the original circuit can be obtained by formula (8).

$$r = \frac{N\sum x_i y_i - (\sum x_i)(\sum y_i)}{\sqrt{N\sum x_i^2 - (\sum x_i)^2} N\sum y_i^2 - (\sum y_i)^2}$$

(8)

The above experiments are repeated many times, and the average Pearson correlation coefficient of four characteristic parameters $r_k, r_d, r_c, r_l$ are obtained by using three methods. The Pearson correlation coefficient is normalized to obtain the weight of each characteristic parameter representing VLSI.
4. EXPERIMENT

The experimental circuit is IBM-HB + Benchmark Suites reference circuit. There are 500-2000 modules in IBM-HB + Benchmark, and the largest module accounts for between 0.9% and 13.6% of the circuit area, which is a large-scale integrated circuit. The main file describing the characteristics of ibm-hb + benchmark circuit is. Network file. It describes the complex network of the circuit, including the number of modules, names and specific connections. In this paper, Java is used to write complex network conversion and processing software to process the complex network files of the circuit, pajek is used to find the characteristic parameters of the changed circuit, and R software is used to do Kruskal test.

4.1. Experimental data

- **Experimental data results**

The experimental circuit IBM-HB + Benchmark consists of 17 circuits, ibm01-ibm04 and ibm06-ibm18. Through the analysis and calculation of the equivalent complex network model, according to the experimental process and repeated experiments, we get the average characteristic parameter change rate of 17 circuits in the benchmark, as shown in Table 1-Table 3.

| TABLE 1: EFFECT OF NODE DELETION ON COMPLEX NETWORK CHARACTERISTICS |
|---|---|---|---|---|---|---|
| Change rate (%) | 5% | 10% | 15% | 20% | 25% | 30% |
| \(<K>\) | 4.87 | 9.45 | 14.87 | 20.38 | 24.62 | 29.91 |
| D | 0.35 | 0.57 | 0.92 | 0.64 | 0.76 | 0.55 |
| C | 0.16 | 0.18 | 0.46 | 0.53 | 0.42 | 0.26 |
| L | 1.48 | 2.25 | 2.43 | 2.88 | 3.08 | 2.48 |

| TABLE 2: EFFECT OF EDGE DELETION ON COMPLEX NETWORK CHARACTERISTICS |
|---|---|---|---|---|---|---|
| Change rate (%) | 5% | 10% | 15% | 20% | 25% | 30% |
| \(<K>\) | 3.74 | 7.54 | 11.56 | 15.35 | 23.77 | 23.65 |
| D | 2.55 | 5.24 | 7.84 | 10.36 | 13.43 | 16.56 |
| C | 5.02 | 10.05 | 15.01 | 20.05 | 24.82 | 29.91 |
| L | 0.76 | 1.38 | 2.02 | 2.69 | 3.74 | 4.06 |

| TABLE 3: EFFECT OF EDGE RE-CONNECTION ON COMPLEX NETWORK CHARACTERISTICS |
|---|---|---|---|---|---|---|
| Change rate (%) | 5% | 10% | 15% | 20% | 25% | 30% |
| \(<K>\) | 0 | 0 | 0 | 0 | 0 | 0 |
| D | 0 | 0 | 0 | 0 | 0 | 0 |
| C | 10.15 | 19.56 | 28.42 | 36.65 | 44.08 | 50.78 |
| L | 12.34 | 17.78 | 20.91 | 23.09 | 24.52 | 26.14 |

Where \(<K>\) is the average degree, D is the network density, C is the average clustering coefficient, and L is the average shortest path.

- **Analysis of experimental data**

It can be seen from Table 1 that when nodes are deleted randomly, the change rate of IBM-HB + average is most closely related to circuit change, almost the same as that of the original circuit. The change of network density and average clustering coefficient is the least obvious. With the change of circuit, there is little change, and the difference between them is not significant. The average shortest change rate with the original circuit is obvious. It can be seen from Table 2 that when the edge is deleted randomly, the average agglomeration coefficient changes most obviously with the circuit, almost the same as the change rate of the original circuit. The average degree, network density and average shortest path all change with the circuit, but the change slows down in turn. It can be seen from
Table 3 that the average clustering coefficient and the average shortest path change obviously with the circuit when the edge is randomly reconnected. There is no average degree and network density because the total number of sides and the number of nodes are almost the same when the edges are randomly reconnected, so the change rate of both is 0.

Among the two methods of edge deletion and reconnection, the relationship between the aggregation coefficient and the circuit topology is closer, because the degree of network aggregation in edge deletion is significantly reduced, and some nodes with large degree and some nodes with small degree appear during reconnection, so that the nodes with large degree occupy a small number, most nodes have small degree and uneven distribution, which leads to the decrease of the degree of aggregation, and the change is also large. Although the change degree of network density change rate is not obvious with several other parameters, it has been slowly decreasing, because whether deleting points or edges will cause the reduction of edges, resulting in network sparsity.

● Different importance of validation characteristic parameters

We have verified our conjecture about the importance of characteristic parameters in the physical design of IC by mathematical method.

TABLE 4. AVERAGE VALUE OF INFLUENCE OF THREE METHODS ON CHARACTERISTICS OF COMPLEX NETWORK

| Change rate (%) | 5% | 10% | 15% | 20% | 25% | 30% |
|-----------------|----|-----|-----|-----|-----|-----|
| <K>             | 4.32 | 8.64 | 13.52 | 17.65 | 24.21 | 26.54 |
| D               | 1.48 | 2.83 | 4.45 | 5.51 | 7.05 | 8.59 |
| C               | 5.25 | 9.86 | 14.87 | 19.54 | 23.52 | 26.95 |
| L               | 4.69 | 7.13 | 8.67 | 9.58 | 10.57 | 10.81 |

We calculated the p-values of Kruskal test of delete point, delete edge, reconnection and the mean values of them, i.e. variance analysis of Table 1, Table 2, Table 3 and Table 4.

The p-value of Kruskal test determines whether a factor will cause significant difference in the results. Generally, the threshold value is 0.05. Generally, Kruskal test assumes that there is no significant difference between the treatment methods. When the p value is less than the corresponding significance level, the original hypothesis is rejected. In this paper, we assume that there is no significant difference among the four characteristic parameters in characterizing the physical design of integrated circuits. The calculated p-values are 0.00011 for deleting points and 0.00646 for deleting edges, Reconnection 0.2002 and average 0.01944, except for random reconnection method greater than 0.05, delete point, delete edge and the average value of the three methods are less than 0.05, rejecting the original hypothesis. Therefore, we can see that the four characteristic parameters have significant differences in characterizing the physical design of VLSI.

4.2. Experimental results

● Pearson correlation coefficient

When one variable increases, the other increases (or decreases), which we call covariance or correlation. Two variables have covariation phenomenon, which is called correlation. Pearson correlation coefficient is a statistical index to reflect the close degree of correlation between variables.

● Characteristic parameter weight

The Pearson correlation coefficient is used to quantify the correlation between the change rate of the characteristic parameters obtained in each method and the change rate of the circuit. In the fourth column, the Pearson correlation coefficients obtained by the three methods are averaged, and the ones < k > and D are the average values of node deletion and edge deletion.

TABLE 5. COMPARISON OF PEARSON CORRELATION COEFFICIENTS OF THREE METHODS

| Pearson correlation coefficients | Node deletion | Edge deletion | Reconnection | Average value |
|----------------------------------|---------------|---------------|--------------|--------------|
| <K>                              | 0.99752       | 0.97548       | -            | 0.98464      |
From table 5, it can be seen that the correlation between the average degree and the circuit change rate is stronger, that is, it is more closely related to the circuit physical topology, followed by the average shortest path, average clustering coefficient and network density. Therefore, it is concluded that when characterizing VLSI, the order of importance of characteristic parameters is $<K>$, $L$, $C$ and $D$ in order.

5. CONCLUSION

The main four characteristic parameters of complex network are average degree, network density, average clustering coefficient and average shortest path. They are all parameters to represent a network topology, but the four parameters can not achieve the overall and global effect and have different importance when they represent the network alone. In characterizing LSI, the importance of the four characteristic parameters is the average degree, the average shortest path, the average clustering coefficient and the network density. In this paper, the importance of different characteristic parameters in the description of IC networks is discussed, which provides a new way for complex networks to describe IC networks and other real networks.

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