Электронные системы

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The Network-on-Chip Quasi-optimal Topology Analysis Method

The article concentrates upon the synthesis of network-on-chip topologies, based on the evolutionary computations method. The optimality criteria of the network-on-chip topologies and a new class of quasi-optimal topologies are proposed. The requirements for quasi-optimal topologies are defined. The genetic algorithm GeNoC for the synthesis of quasi-optimal network-on-chip topologies with the number of nodes up to 100 is developed. By using the mathematical methods of optimization the analysis of the obtained quasi-optimal topologies is performed. The importance coefficients correction method of the objective function in the synthesis of quasi-topologies is proposed; as a result, the difference in their performance compared to theoretically possible optimal topologies is reduced up to 1,8%. References 7.

Keywords: *networks on chip, quasi-optimal network-on-chip topologies, evolutionary computation method, genetic algorithm.*

Introduction

The continuous development of modern systems-on-chip led to the emergence of multiprocessor systems and, therefore, a new class of systems – networks-on-chip (NoC). NoC communication subsystem takes considerable resources of the chip and is energy-intensive [6]. This is primarily determined by the NoC topology that stipulates the necessity of finding the optimal solutions for the NoC topology construction.

The Topological Approach for the NoC Synthesis

In general, the NoC synthesis process is performed by the reflection of an architecture problem characteristic graph on the NoC architecture, defined by its topology. Thus, an optimal topology choice for a specific task determines the efficiency of the entire system. Usually, the problem of the efficient NoC topology synthesis is resolved as following: it is selected either a specialized topology, in case when the information about the future computational tasks to be performed by the developed system is known, or it is used a regular or platform-dependent topology if the synthesis is carried out on the basis of the multiprocessor chip [3, 5]. Therefore, it is reasonable to combine both approaches to the NoC synthesis, based on specialized and regular topologies by applying the pre-defined optimal or quasi-optimal topologies that will reduce the backwards of both approaches by combining their advantages.

The Criterion of NoC topology Efficiency

For the synthesis of optimal NoC topologies it is necessary to formulate an optimality criterion. The basic optimality criteria of NoC topologies are: minimization of the average distance between the nodes and minimization of the number of nodes connections, the criteria of minimum diameter of the graph and the minimum degree of vertices achievement for a given number of nodes [2, 3]. The proposed criteria are contradictory. Consequently, the use of the principle of minimization of the weighted sum of single-factor criteria is proposed and the additive integral criterion of NoC topologies efficiency is formulated [7]:

$$optK = k_1 \cdot St_{max\_norm} + k_2 \cdot D_{norm} + \\ + k_3 \cdot L_{av\_norm} + k_4 \cdot Ed_{norm} \quad optK \to \min,$$

where $\sum_{i=1}^{4} k_i = 1$ – criteria importance coefficients; $St_{\max\_norm}$, D_{norm}, L_{av_norm}, Ed_{norm} - are normalized to the appropriate values of the regular topology (mesh or torus).

This criterion is a universal one. By setting the coefficients of importance it is possible to choose an optimization strategy and even to remove some unimportant single-factor criteria referring them to the restrictions region.

Due the lack of resource cost for the synthesis of the efficient topologies for NoCs there proposed a new quasi-optimal class of topologies. A quasi-optimal (suboptimal, pseudo-optimal) NoC topology is a topology for a given number of vertices and limitations, which is close to the theoretically possible optimum topology according to the certain criteria. The criteria of optimality correspond to the integral criterion (1), but the methods by which the quasi-optimal topologies are synthesized enable finding the local optimum and do not guarantee achieving of the most optimal results. They only give the results which are close to the optimal ones. There formulated the criterion of quasi-optimality which measures of closeness of quasi-optimal topology to the optimum which is a difference between the value of the objective function (1) of the found topology to the theoretically possible value of the objective function for the optimal topology. On the basis of expert assessments the threshold value for determining of quasi-optimality is set to 5%.

The Evolutionary Method for the Synthesis of Quasi-optimal NoC Topologies

There is a need to apply a heuristic method which gives an opportunity of a certain probability in generating the topologies for a big number of nodes and those which meet the quasi-optimality criterion. The genetic algorithm for the synthesis of quasi-optimal topologies, implemented in Matlab 7 environment as a GeNoC project is proposed [4]. The developed genetic algorithm gives the possibility of adjustment of many parameters and to perform visualization of an algorithm operation by displaying of the information about the current state of the evolution via the command line output and the image of the graph with the best found configuration. By using GeNoC it is synthesized a number of quasi-optimal topologies with the number of units up to 100. Combining this approach with the parallel computing method makes a possibility for further acceleration of the topology synthesis and receiving the quasi-optimal topologies with bigger number of units.

The Analysis of Quasi-optimal Topologies, Synthesized by GeNoC

To assess the quasi-optimal topologies, it is necessary to find the approximated characteristics of the theoretically possible optimal topologies for a given number of nodes and constraints which can be done by formulating the linear programming problem.

In general, the problem of the linear programming for minimization of function with n variables and m constraints is formulated as follows [1]:

$$\sum_{j=1}^{n} a_{ij} x_i \geq cost_i \,,\ i = 1 \ldots m;\ \ x_j \geq 0,\ \ i = 1 \ldots n; \qquad (1)$$

where x_i – approximated variables; C_i, a_{ij}, $cost_i$ – constants.

To formulate the linear programing problem with the tool of GeNoC it is synthesized a NoC topologies field for the number of nodes of 25 with the different coefficients of importance $k_1,\ldots,k_4$ of the objective function (1). Among the elements of the field of the synthesized topologies it is selected the samples for the topologies with the best characteristics which are listed in table 1. As normalizing values, according to (1) there selected characteristics of a mesh topology for 25 nodes.

By analyzing the obtained quasi-optimal topologies on the proximity to the optimum the variables $x_1 \ldots x_4$ in the formula (1) are taken as the unknown values of the degree of vertices, diameter, average distance and the number of connections between vertices at which the objective function is minimal. The coefficients a_{ij} are set as the ratio of relevant coefficients of importance to the characteristics of the mesh topology and $cost_i$ – as values of the objective functions for the appropriate topologies. The conditions of $x_j \geq 0$ can also be refined by analyzing the obtained topologies. Thus, the classical problem of the linear programming is formulated [1]. It is resolved in MatCad. As a result, the characteristics of the optimal topologies are determined.

The quasi-optimal topologies, synthesized under the same coefficients of importance are compared with the optimal ones. The deviation from the optimum value of the objective function which determines the efficiency of the synthesized quasi-optimal topologies amounts to no more than 3,7% and is less than the prescribed limit of 5%, according to the quasi-optimality criterion. This demonstrates the high efficiency of GeNoC algorithm which in combination with a significant acceleration of the synthesis of NoC topologies, compared to other methods stipulates the possibility of usage of evolutionary computations method for the synthesis of NoC quasi-optimal topologies with the number of nodes amounting the hundreds.

The analysis of the obtained topologies with different coefficients of importance shows that there is a possibility of the synthesis of various topologies with a reduced number of connections or the average distance between nodes and the diameter that can be used by developers when synthesizing NoC topologies for the specific conditions in terms of limitation in hardware resources and minimal throughput.

The Importance Coefficients Correction Method

The linear programming problem can be formulated in a different way choosing important factors $k_1,\ldots,k_4$ in the formula (1) as the unknown approximated variables. Then the coefficients are normalized values $C_1 \ldots C_4$ and a_{ij} will be the maximum degree of vertices, diameter, average distance and the number of connections between the nodes of NoC, derived from the characteristics of the synthesized quasi-optimal topologies. Equation (1) implies another restriction: $x_1 + x_2 + x_3 + x_4 = 1$.

The formulated linear programming problem is solved in the MathCad. As a result, returned values of the coefficients of importance of the objective function take the minimum value. The analysis of the obtained topology shows that the performance of its quasi-optimality coefficient is only 1,8%. Thus, the use of this method makes it possible to adjust the coefficients of importance in the synthesis of topologies by using GeNoC algorithm and improve the results of synthesis, reducing the obtained difference of the optimal topologies from 3,7% to 1,8%.

Conclusion

The usage of irregular quasi-optimal topological solutions for the synthesis of NoC which is a compromise between regular and specialized topologies is proposed.

An integral criterion of NoC topologies efficiency is defined. The definition of quasi-optimal topologies and quasi-optimality criterion are specified. A new genetic algorithm GeNoC is proposed and the new quasi-optimal topological network solutions with the number of nodes up to 100 are obtained.

By means of the mathematical optimization methods there performed an analysis of quasi-optimal topologies for the number of nodes of 25, synthesized by GeNoC and it is shown that they only have less than 3,7% worse performance characteristics, compared to the approximated optimal topologies. An importance coefficients correction method is proposed; as a result, a new topology with the 1,8% quasi-optimality coefficient is obtained. This demonstrates the high efficiency of the quasi-optimal topologies, synthesized by GeNoC algorithm.

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Метод аналізу квазіоптимальних топологій мереж на кристалі

У статті розглянуто синтез топологій мереж на кристалі на основі методу еволюційних обчислень. Запропоновано критерії оптимальності топологій мереж на кристалі і новий клас квазіоптимальних топологій. Сформульовано вимоги до квазіоптимальних топологій. Розроблено генетичний алгоритм GeNoC для синтезу квазіоптимальних топологій мереж на кристалі з кількістю вузлів до 100. За допомогою математичних методів оптимізації виконано аналіз отриманих квазіоптимальних топологій. Запропоновано метод корекції коефіцієнтів значущості параметрів цільової функції при синтезі квазіоптимальних топологій, що дозволило зменшити різницю в їхніх характеристиках порівняно з теоретично можливими оптимальними топологіями до 1,8%. Бібл.7.

Ключові слова: *мережі на кристалі, топології квазіоптимальних мереж на кристалі, еволюційний метод обчислень, генетичний алгоритм.*

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Метод анализа квазиоптимальных топологий сетей на кристалле

В статье рассматривается синтез топологий сетей на кристалле на основе метода эволюционных вычислений. Предложены критерии оптимальности топологий сетей на кристалле и новый класс квазиоптимальных топологий. Сформулированы требования к квазиоптимальным топологиям. Разработан генетический алгоритм GeNoC для синтеза квазиоптимальных топологий сетей на кристалле с количеством узлов до 100. С помощью математических методов оптимизации, выполнен анализ полученных квазиоптимальных топологий. Предложен метод коррекции коэффициентов значимости параметров целевой функции при синтезе квазиоптимальных топологий, что позволило уменьшить разницу в их характеристиках по сравнению с теоретически возможными оптимальными топологиями до 1,8%. Библ. 7.

Ключевые слова: *сети на кристалле, топологии квазиоптимальных сетей на кристалле, эволюционный метод вычислений, генетический алгоритм.*

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