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PRACTICAL CLASSIFICATION TOPOLOGICAL STRUCTURES OF COMMUNICATION NETWORKS FOR MULTIPROCESSOR COMPUTER SYSTEMS

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Abstract: *Proposed by the working version of practical classification topological structures of communication networks for multiprocessor computer systems. Any n-dimensional non-full mesh structure presented here as the result of some operations on any basic graph of the set, including one-dimensional non-full mesh simple graphs and n-dimensional realization of the generalized full mesh structure. The main classification criterion, which was refined earlier, is the notion of dimension topological structure that eliminates the shortcomings and contradictions of the, well-known, authors such classifications.*

Keywords: *multiprocessor computer system, communications network, classification of topological structures, the dimension of topological structure.*

1 Introduction

The apparent trend in the development of multiprocessor computer systems (MPCS) is a constant increase in the number of processing elements and computational nodes. Accordingly, becoming more complex their communication networks (CN). Early MPCS had a relatively a small amount of processors and memory modules, which are connected to each other by a simple CN types: bus, ring, binary tree, rectangular lattice [1-3]. CN of the modern MPCS based approach on more complex toroidal and tree types (for example, 3D-torus or "fat tree") [1, 4-7].

The initial stage of the designing CN MPCS is its topological synthesis, i.e. the choice of intermodule communication graph. The problem of the topological synthesis of CN is consider as a choice of the best variants of distribution some connections I between the predetermined amount nodes N of the topological structure (TS) graph by constraint-driven on the values of certain topological metrics (TM) network (for example, the order of nodes d). Well, it is generally, consider a variant of the graph, that has the least value of the maximum diameter D and the maximum width bisection B [2,8,10]. Methods of topological synthesis should be improved in connection with TS CN is complicated and increases.

Undoubtedly, at the stage of study selection an intermodule communication graph MPCS, highly desirable is practically meaningful classification of TS CN.

In order to classification TS CN was practically useful for designer, it is, in our opinion, should meet the following requirements:

- as the classification characteristics, to be used unambiguously defined and practically significant TM CN;

- classification should be sufficiently formalized and to allow its expansion and addition.

It is desirable that the direction of its extension is visible effective methods of topological synthesis CN, possibilities and rules optimum TS scaling, methods for producing complex structures that based on more simple.

In the absence, in the well-known authors of literature classification, fully meet these requirements, the research topic is quite relevant.

As previously indicated, the mathematical classification of the CN [8,9,11], in connection with the desire of the author to the highest completeness and generality, look complicated; classification characteristics are not always correlate with the main TM CN. As a rule, they can only tell designer to the approximate direction of the search.

On the other hand, common to the special and educational literature "practical" classifications of CN is too simplistic, incomplete and contradictory [1,3,5]. It has been shown [12] that the shortcomings and contradictions of the classifications of this type are due, in particular, with subjectivity (multivariate) imaging TS CN and, as a consequence, incorrect use a classification characteristic such as their dimension. Accordingly, they can be eliminate by clarifying the concept of the dimension of the TS and the rejection of their identification with the traditional representation about the dimension of the Euclidean space.

It was also asked to determine the dimension of the TS CN R as the absolute minimum connectivity structure, that is, the number of completely alternative ways (which do not overlap on any edge of the graph) of any length between any two nodes having the minimum order for this structure d_{min}. That is, by geometric dimension is can be expressed as the width of the section CN that crosses the minimum number of connections. Specify that if the width of any cut is not less than the minimum order of node for this structure d_{min} (this condition is satisfied for almost all TS CN), then $R=d_{min}$. It is obvious that for any univalent TS, all the nodes that have the same order, $R=d$.

Refined in this way the concept of dimension TS CN is an objective indicator, since it does not depend of way to imaging the structure. Furthermore, this criterion is practically important, because for the most common in modern MPCS univalent CN coincides with the order of the nodes, that is, with the number of communication ports.

Accordingly, it was propose [12] to classify TS by the dimensions as follows:

- 0-dimensional (trivial graph);
- 1-dimensional (line array, simple trees, star);
- 2-dimensional (ring, 2-dimensional realization of the n-dimensional topologies, for example, 2-dimensional lattice);
- n-dimensional (non-full mesh or structure of variable dimensional, specific implementations of which are, depending on the number of nodes, different dimension $n<N-1$: hypercubes, chordal ring structures (circulants), multidimensional lattice (n-lattice or hyperlattices), complex structure which based on star-shaped and tree base graphs (hypertrees and multitrees), toroidal TS (hypertors or n-tors) and so on);
- (N-1) - dimensional (full mesh).

This classification seems to be quite acceptable for educational applications, as it eliminated the ambiguity and contradictions mentioned earlier. However, from an engineering point of view, it seems haven't detailed, as almost all TS of modern MPCS on which the CN built are non-full mesh n-dimensional.

The aim of this work is to provide, based on the proposed approach, working (basic) version of the classification TS CN, which meets the requirements set earlier. For further detailed classification proposed an "evolutionary" approach, which based on a process for preparing TS from the simple to the complex of some generalized operations. In this case a group of 1-dimensional and full mesh structures of different dimensions can be seen as a group of basic graphs for construct TS by any dimension $2\le R<N-1$.

2 Properties of basic graphs

The full mesh TS, in comparison with any other structures, has some unique topological properties [10,13,14]. Firstly, its dimension $R=d=N-1$ is identically determined by the number of nodes N and the structure a maximum possible for a concrete value N. The group of all full mesh graphs with any number of nodes may be define as a group of n-dimensional realization of the generalized full mesh structure. Then, for example, trivial graph is 0-dimensional its implementation, "segment" of the two nodes and one edge – 1-dimensional, "ring" of minimum size N=3 – 2-dimensional, etc.

Accordingly, compared to any non-full mesh n-dimensional TS, dimension of full mesh TS may be implementations in the widest range of $0 \le R \le N-1$.

Secondly, any non-full mesh TS, if adding it her links up to the maximum possible number (duplication excepted) becomes full mesh or vice versa – any non-full mesh TS may be obtained from full mesh of appropriate size by eliminating the "extra" links. The non-full mesh TS, obviously, can be have value of dimension within the somewhat narrow range of $1 \le R \le N-2$, as the dimension equal to the boundary values 0 and $N-1$ have only realization of full mesh topology.

These properties allow to consider the set of n-dimensional realizations of the generalized full mesh structure as the basis, "topological scale" for the construction of classification TS CN, since for any value of R of the previously specified range, obviously, there is only one implementation of a full mesh topology. For example, among the 1-dimensional structures such implementation is a "segment" of the two nodes and one edge.

The 1-dimensional non-full mash TS (linear TS, star or terminal topology, simple trees) has a number of common properties (nonunivalent, the minimum possible number of edges for connectivity of the graph $I=N-1$, no loops) [10,13,14]. However, they differ significantly in degree univalent for any sufficiently large number of nodes N.

To assess the degree of approximation nonunivalent to univalent TS, which has the same number of nodes and the dimension $R=d_{max}$, has previously been proposed [15] to use the coefficient of univalent:

$$K_u = \frac{2I}{d_{\max} N}.$$

It has been shown [15] that on the basis of trends changing coefficient of univalent with unlimited increase N, 1-dimensional non-full mesh structures can be divided into three classes:

- linear TS is "extremely univalent" (K_u increases and converges to one);

- a simple trees with any value of the parameter branch, which can be defined as the ratio of the number of nodes in two adjacent tiers of the structure are substantially nonunivalent (K_u increases and tends to the value, which is always much less than one);

- terminal topology is "extremely nonunivalent" (K_u decreases and converges to zero).

Plots of the function $K_u=f(N)$ for the 1-dimensional non-full mesh TS shown in Fig. 1 [15].

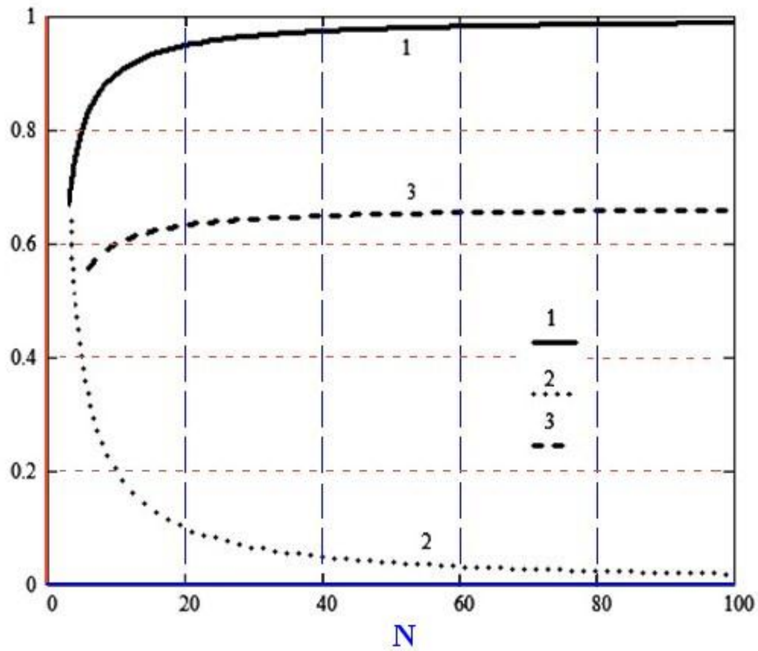

Fig. 1 – Plots of the function $K_u = f(N)$ for the 1-dimensional non-full mesh TS
(*1 – liner TS; 2 – terminal TS; 3 – binary tree*)

On the basis of the uniform-sized base graph with the help of copy operations (with "fusion" of nodes or without it [10]) and the next connection of some nodes received copies by introduction of additional toroidal linkages and so on, they can be prepared by various n-dimensional non-full mesh TS – as a univalent and nonunivalent.

Using nonunivalent TS CN in modern MPCS is considered inappropriate, in connection with their real nodes having the order of $d<d_{min}$, unused communication ports. The ratio of the number of unused communication ports to the total number of Nd_{max} regarded as a relative excess topological cost [8,15].

Converting nonunivalent TS in univalent made of quite simple and universal method – well-directed addition of these links annular (toroidal) type. Note that this conversion, in most cases, accompanied by improvement of the topological properties of the structure (a decrease in the maximum diameter and an increase in the width of the bisection [10]). Thus, nonunivalent TS may be considere as basic graphs for constructing of univalent structures [16]. That is why the presence of nonunivalent structures in practical classification TS CN, in our opinion, is fully justified, but division of TS on univalent and nonunivalent should not be seen as a major classification characteristic.

On the other hand, the effect of the topological properties of the basic graphs on properties of complex structures derived from them, no doubt. Accordingly, a plurality of 1-dimensional TS, along with a variety of implementations of the generalized full mesh structure can be use, as a group of basic elements for the construction of the general classification TS CN.

3 The version of the classification TS CN

The proposed working (basic) version of the classification TS CN shown on Fig. 2 in graphical format.

The sequence of n-dimensional realizations of the generalized full mesh TS, which arrange in order of increasing dimension, forms the left side of the classification, respectively, all non-full mesh structure – it is right side. The zero dimension has only a trivial graph, TS that has dimension $R=1$ form the level of simple basic graphs. Emphasize, that nontrivial graph of minimum size $N=2$, has topological properties is full mesh 1-dimensional TS, any non-full mesh structure is not contain fewer than three nodes. Accordingly, any class of non-full mesh TS has in its structure the simple structure by the size $N_{min}\geq 3$, the specific values of N_{min} for structures of different classes may also vary. For example, non-full mesh linear structure of minimum size $N=3$ can also be viewed as just a simple "star", however, in our opinion, should not consider it just a simple tree (said TS can be regarded as a basic graph for the binary tree by its multiple copy with merging some nodes).

The full mesh simple trees can be defined as TS, which has at least three tiers, where the root tier is only one node, whose order is equal to the branching parameter $k_t\geq 2$; nodes of intermediate tiers have the order k_t+1, and "leaves" are first-order nodes. The number of nodes on each tier is equal $k_t l$, where l – the ordinal number of tiers, if the root tier count by zero. Accordingly, the simplest TS of this class should be considered a three-tiered binary tree ($k_t=2$) by size of $N=7$.

In the incorrect determination of the linear structure the minimum size of which $N=3$ as a simple binary tree, is easy to be convinced, for example, analyzing the dependence of $K_u=f(N)$ for 1-dimensional non-full mesh topologies, graphics which are shown in Fig. 1. So, the graphics for linear and terminal TS have a common origin at the point ($N=3$, $K_u=2/3$). However, it is obvious that this point does not belong to a binary tree graphic.

Most generic operations by which one TS can obtain from other (including the elimination part of links of the full mesh TS) are shown in Fig. 2 by arrows.

TS by dimension $R=2$ can be obtained by copying the basic 1-dimensional graphs, followed by a compound (or merge) some nodes of received copies, or the introduction of a toroidal (ring) link in a linear structure. Thus, at a level $R=2$ begin some classes of n-dimensional non-full mesh TS, namely rectangular n-lattice, complex structures on the basis of simple tree and star.

The full mesh TS size of which $N=4$, respectively, the dimensions $R=3$, is the basis of the class chordal ring structures or circulants.

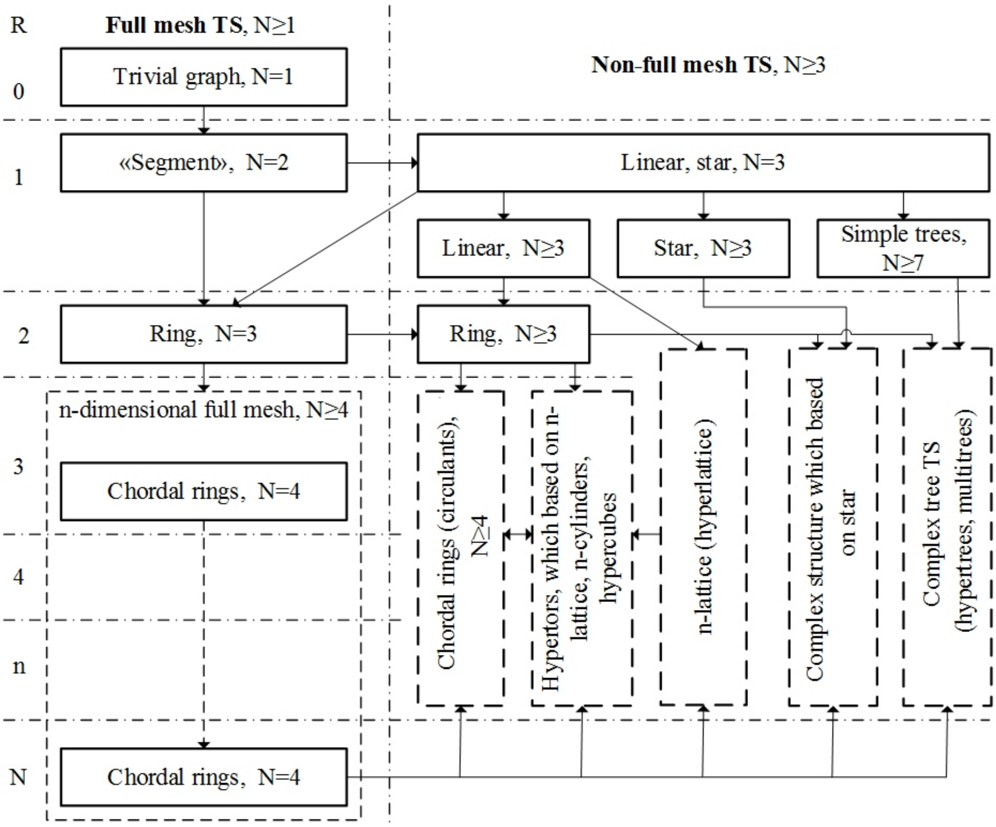

Fig. 2 – Working (basic) classification version TS CN

Also on this level it begins class of hypertorus, which basis on rectangular n-lattice, if consider the three-dimensional cube is the simplest instance of the specified class. In this class can be select a subclass of n-cylinders (non-full mesh hypertorus, which based on n-lattices, where the number of nodes at least in one dimension equal to two) [18]. Then hypercubes can be defined as the simplest hypertorus based on n-lattice (or simplest n-cylinders) in which all, without limitation, the number of nodes is two in all measurings. On the other hand, [17] hypercubes can be consider as a subclass of circulants. Accordingly, the composition of classes from non-full mesh TS allocated in Fig. 2 by dashed lines, and the connections between them may be refine by further research.

4 Conclusions

In the proposed classification TS CN MPCS a main feature is a refined concept of the dimension of the structure, which allows eliminating the shortcomings and contradictions of famous authors such classifications. Any n-dimensional non-full mesh TS is considered here as the result of some generalized operations on any basic graph of the set, including one-dimensional non-full mesh simple graphs and the n-dimensional realization of a full mesh structure. The main direction of future research is the development of advanced, indeed practically useful for designer classification TS CN that based the proposed working version, which requires its further detailing and formalization. In accordance with the proposed approach in the first place should be clarified and precisely the composition of classes n-dimensional non-full mesh TS and define a minimum set of generic operations for the construction of these structures on the basis of a set of basic graphs.

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Практическая классификация топологических структур сетей связи для многопроцессорных компьютерных систем.

Аннотация: Предложен рабочий вариант практической классификации топологических структур коммуникационных сетей мультипроцессорных компьютерных систем. Любая *n*-размерная неполносвязная структура здесь рассматривается как результат выполнения некоторых операций над каким-либо базовым графом из множества, включающего одноразмерные неполносвязные простые графы и *n*-размерные реализации обобщенной полносвязной структуры. Основным классификационным признаком является уточненное ранее понятие размерности топологической структуры, что позволяет устранить недостатки и противоречия известных авторам подобных классификаций.

Ключевые слова: мультипроцессорная компьютерная система, коммуникационная сеть, классификация топологических структур, размерность топологической структуры.

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Практична класифікація топологічних структур мереж зв'язку для багатопроцесорних комп'ютерних систем.

Анотація: Запропонований робочий варіант практичної класифікації топологічних структур комунікаційних мереж мультипроцесорних комп'ютерних систем. Будь-яка *n*-розмірна неповнозв'язна структура тут розглядається як результат виконання деяких операцій над яким-небудь графом з множини, що складається з одноразмірних неповнозв'язних простих графів та *n*-розмірних реалізацій узагальненої повнозв'язної структури. Основною класифікаційною ознакою є уточнене раніше поняття розмірності топологічної структури, що дозволяє усунути недоліки та протиріччя відомих авторам подібних класифікацій.

Ключові слова: мультипроцесорна комп'ютерна система, комунікаційна мережа, класифікація топологічних структур, розмірність топологічної структури.