TECHNICAL SCIENCES

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Some aspects of constructing of the high-efficiency multiprocessor system

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Abstract. The paper is devoted to the modeling of high-performance multiprocessor architecture for data processing systems used to solve problems with an expandable calculations' area. The proposed system is characterized by high reliability and high energy efficiency. The system contains a separate reconfigurable network for the exchange of data between computing nodes, managed switches. The system also provides network booting nodes and redundancy mechanism of key components.

Keywords: *multi-processor computer system, managed switches, reconfigurable network, compute nodes, memory buffers, components of a computer system*

Introduction. The need in high-performance computing in the world belongs to the fundamentals of the strategic potential and has important scientific, technological and national economic significance. To date, there are two basic methods of increasing productivity and performance of computing systems: the use of more advanced element base; parallel execution of computational operations.

The first method involves a very significant investment. Experience of the firm *CRAY*, which has created a supercomputer based on gallium arsenide showed that the development of a fundamentally new element base for high performance computing systems is a daunting task even for such big-name corporations. The second method dominates after the announcement of the government program "*Accelerated Strategic Computing Initiative*" (*ASCI*) in the United States.

Given the above, we note that in recent years the process of creating high-performance systems developed mainly in one direction: combining many parallel processors for the solution of a large and complex problem [1-4]. In this regard, one often identifies today a concept between a supercomputer and parallel (multiprocessor) computer system. To build supercomputers one takes serial microprocessors provided with their local memory and connected via a communications medium. This architecture has many advantages: if necessary, one can add processors, increasing the productivity of the cluster; if financial resources are limited or the necessary computing power is known in advance it is easy to select the desired system configuration. The name of such systems emphasizes theoretically unlimited scalability devices of this class.

Analysis of ways to develop high-performance systems shows that the real turning point in mastering the parallel computing technologies can be achieved in the developing of additional (actually base) level in the hierarchy of capacities of hardware multiprocessor computing systems *MPP*-architecture or the personal computing clusters. Thus, it is proposed to establish the foundation of the pyramid hardware technology for parallel computing as personal computing clusters similar to the existing instruments with traditional technologies in the form of sequential computations as the *PC*. As computers have ceased to be exotic after widespread of the *PCs* as well mastering techniques of parallel computing is only possible as a result of widespread use of the *PCs*. In this case, if the beginning of the common use of *PCs* belongs to the other half of eighties , the mid-first decade of XXI century should be considered the beginning of the spread of personal calculable clusters in the form of multiprocessor computer systems with distributed memory. Scope of these systems application is very wide: mastering the parallel computing technology, creation and debugging of parallel programs, including problem-oriented packages and libraries, as well as run of the model developed software.

This paper shows that the problems that arise when developing parallel computing systems usually are paramount and require in-depth study and research. Indeed, a distributed (parallel) computer modeling covers the entire spectrum of modern computing: supercomputers, cluster computing systems, local and wide area networks, etc. In addition, distributed modeling permits to solve problems that require large amounts of *CPU* time to integrate mathematical models processed on different (including geographically distant) computer systems. In this regard the problem of designing computing clusters, as well as the development of numerical algorithms for parallel processors are relevant and paramount.

Statement of the problem. The work is devoted to the modeling of high-performance multiprocessor architecture of data processing systems used to solve problems with the expanding field of computing. At the same time there is difference grid dimension $\boldsymbol{M}$; time of computing the problem by using a single-processor system is determined by the value $\boldsymbol{t}$. This parameter is not determinative. The principle is increasing of the grid size, wherein more than one that may be processed in the memory of one processor. This procedure is decisive for a more detailed calculation or getting some new effects of the investigated processes. To solve this class of problems we propose multi-processor system which is characterized by high reliability and high energy efficiency. The technical result is achieved due to the fact that the system contains a separate re - configurated network for the exchange of data between computing nodes, more manageable and running in parallel switches, the intermediate buffer memory switches. Such a system also provides nodes' network booting and the mechanism to reserve key components.

Analysis of recent research and publications. In modern conditions the cluster systems are constructed by use of computing nodes based on standard processors connected by high-speed system network (interconnect), and, usually, by auxiliary and service networks. However, in recent years the leaders in manufacturing hardware computer technology offer a form factor: in particular, the companies *IBM*, *LinuxNetworx* and others have at their disposal a cluster solution built on the basis of so-called blade technology. In the practice of parallel computing the following problem is considered: there is difference grid dimension ***M***; computation time when using a single-processor system is determined by the value ***t***. This parameter is a decisive and critical. Principle is to reduce the time for solving the problem. The procedure itself is determinant for design of new processes to meet the challenges of medicine, military affairs, and others.

There are many computing systems with the shared memory which are oriented on solving of the task. These systems involve the processors united with definite commutation environment. Among them there are *Intel Paragon, IBM SPI, Parsytec, Blackford MultiCore* and others.The differences between these systems depend on the type of processors and the structure of communicative area. The typical example of such systems may be presented by the cluster Blackford MultiCore [5].

Nevertheless, it should be noted the following disadvantages of a multiprocessor system:

1. Low real productivity solutions of strongly coupled tasks.

This disadvantage due to the fact that the peak performance of the compute node is equal to 37.28 ***GFLOPS***, and the communication environment for all nodes in the cluster system could exploit one Gigabit network.

2. The high cost of the system.

Lack of is predetermined by application processors specialized components, housings format $1U/2U$, specialized air conditioning systems, high-power *UPS* systems, and more.

3. High power consumption and high operating costs of the system. The reason is the need for high energy consumption for infrastructure the entire cluster system (8 *kVA*, 10 *kVA*),which increases the cost of holding the cluster. To create conditions for the reliable operation of the cluster we need to reserve the necessary components to form a cluster, and this, in turn, increases the cost of operating a cluster system.

4. Complexity of the cluster operating.

The reasons for this lack can be explained by two factors. Firstly, there is a need to retain staff of certified specialists for adjustment, operation and maintenance of the cluster system. Second, the operating system is installed on each of the compute nodes, so in the event of failure or the need for changes in the system or software one has to migrate each node separately. All this leads to an increase in system downtime.

It is also known that the efficiency of the parallel computations significantly depends on many factors, one of the most important is the specificity of the data transfer between neighboring nodes of a multiprocessor system, because this slowest part of the algorithm can negate the effect of increasing the number of processors used. These questions considered to be critical in the process of modeling of a wide class of problems with the help of modular multiprocessor systems and today these are being addressed by many researchers [4, 5, 10].

In practice of parallel computing the known module of a high effective multiprocessor system on high alert contains [6] one master node (*MNode*001) and five slave-computing nodes (*NNode*001, *NNode*002, *NNode*003, *NNode*004, *NNode*005), three controlled switch (*SW*1, *SW*2, *SW*3), intermediate buffer memory switches, reconfigurated network for the data exchange between computing nodes, virtual *LANs*, the redundancy mechanism of key components, and also provides network booting nodes. Commutative network multiprocessor computing system operates in two modes: having topology of the star type or of the circle one. This cluster system is based on blade technology. It is a densely packed module processor of a blade type installed in the rack. The rack inside contains nodes, devices for efficient connection of the components of the control equipment internal network systems, etc. Each blade cluster runs under its copy of the standard operating system. The composition and output nodes may be different within the same module, and a homogeneous unit is considered in this case. The interaction between the nodes of a cluster system is installed using the programming interface, i.e. specialized function libraries. In designing the multiprocessor system special attention was paid to the possibility of extension or modification of the cluster in the future.

Among the disadvantages of such a system we can call:

1. Inability to use such a system for solving problems with an expandable calculations' area. The disadvantage is predetermined by the fact that the communication environment for all nodes of a cluster system is designed to use one-gigabit network. In solving problems with an expandable area calculations we will meet the overload of network resources of the system as so the processors will be forced to idle and the system will work only on the organization of the data exchange between its nodes.

2. Low real performance for tightly coupled tasks. This disadvantage is connected in a one-gigabit network latency at which most of the time will be spent for data exchange and synchronization .

3. Limited and specially oriented range of problems that can be solved with the help of such a system. This disadvantage is due to the fact that the solution of problems with using commutative computer network system is based only on the use of two modes. The first mode simulates the network star-topology, the second simulates the circle-topology ***t***. These modes are oriented to implement data exchange limit depending on a restricted class of problems solved by the proposed cluster.

4. Limited expandability of a multiprocessor system. The reason for this deficiency is caused by using one-gigabit network, so during expansion of a cluster system the number of its blades will be limited because of an overload of network resources.

Unsolved part of the problem. The existing multiprocessor computing systems are not focused on solving tasks with an expanding field of computing. Acting methods of analyzing the effectiveness of multiprocessor systems do not allow to determine the optimal number of nodes to solve the mentioned above class of problems. At the same time the proper development studies on the analysis of the influence of the network interface on the efficiency of such systems have not acquired. In addition, for evaluating the effectiveness of a computer system the basic analytical relations through the parameters of the studied system are not presented.

The purpose of the study is to provide a multi-module computer system, the real efficiency and productivity of which would peak at solution strongly coupled problems and problems with an expanding field of computing. And in addition, the system must have high reliability and high energy efficiency. Units of the claimed device must be equipped with the help of computer technology of mass production. These solutions allow to design the claimed system in universities, research organizations, research centers. Due to the significant demand for blade configuration systems within the domestic market the further development of blade technology for the construction of the cluster computing system should be acquired.

Basic results of research. Design features of the multiprocessor system. Multi processor module system includes one master node (*PM*001) and slave-computing nodes (*PN*001, *PN*002, *PN*003, ..., *PN*00N), two controlled switches (*KGI*, *KIB*), intermediate buffer memory switch *KGI*, reconfigurated network for communication between computing nodes, *VLANs* core redundancy components and also provides a network boot nodes. Commutative multiprocessor computing system operates in six modes: star, circle, ruler, complete graph, grid, lattice closed. These modes have been focused on the implementation of the limit data exchange representing the particular problems which are solved using the proposed system. Fig. 1 shows its block-diagram.

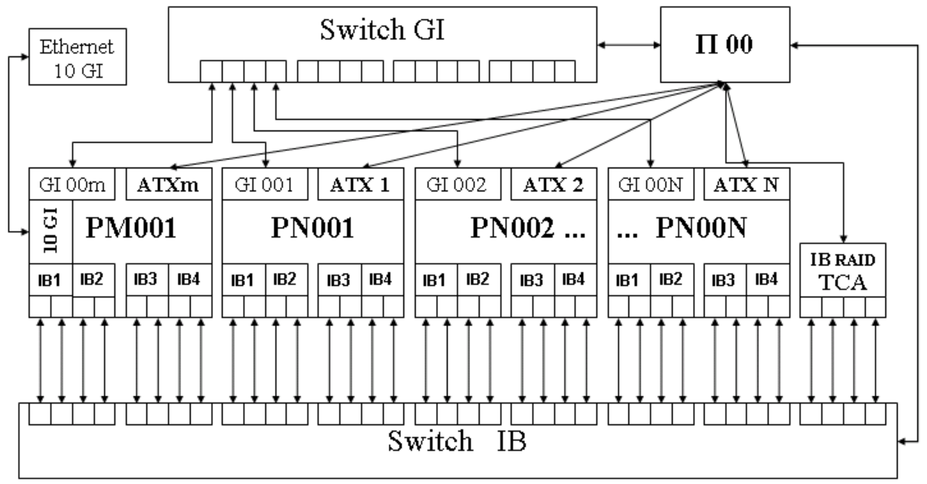

Fig.1. Block diagram of the multiprocessor system

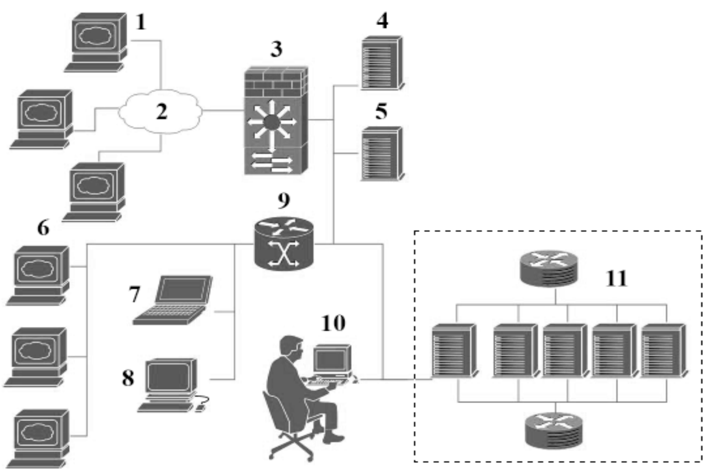

Fig.2. Communication modes desktop PC with the multiprocessor system

Distant access to the resources of the system can be provided via the multiprocessor workstations (1) connected to the *INTERNET* (2) through a personal firewall (3) of a university network. Internal access to the resources of the system is ensured through multi stationary station working groups and laboratories of a university (6), personal mobile laptop station (7), the experimental laboratory (8) and through personal workstation operator of the multiprocessor system (10).

Features of functioning of a module in the multiprocessor computer system. After the power supply to the power supply master node (*ATXm*) and external signal *START* of control module *P00* we notice the startup and initialization of the master node module system. Loading of operating system directly can be performed either from the hard disk or *CD / DVD*-devices. After downloading of the operation system the specifically oriented configuration script that sets up the work of *DHCP*-server also runs. In addition the number of computing nodes of the system is determined on this step and, if necessary, there is access to the Internet environment or to an external network. Also the basic parameters are determined. Consistent power supply to (*ATX*1 – *ATXN*) and initialization of slave-nodes reduces the required power for unit *UPS*, runs all the computing nodes and slave-load operating systems in them. After downloading and debugging of all computing nodes of the cluster the appropriate script is finalized and the system is ready to perform parallel computations.

Master node (*PM*001) through the switch *KGI* provides the direction of data related to the management, diagnosis and downloading of the tasks' conditions. In turn, the slave-nodes respectively to the solving algorithm, implement the mode of computation required. Exchange of data between computing nodes is organized as a separate network with the help of a managed switch *KIB*. To maximize the efficiency of a cluster system, we have to reconfigurate the second network structure respectively the specifics tasks. Send / receive data in slave-nodes takes place without buffering using a managed switch *IB*. Intermediate and final results of the calculations are sent to the master node via a managed switch Infiniband *KIB*. In this case, management and transfer of relevant data from the slave-node occurs at using the *AC* adapter *HCA* (*Host Channel Adapters*). Directly data storage for further processing is performed via the *AC* adapter *TCA* (*Target Channel Adapters*).

Features of functioning for a module multiprocessor computer system. At the first stage of the research we consider how to build the interface and what are the main modes of operation. For convenience we note that the computer network system has two main characteristics: bandwidth and latency. The capacity of the computer network is defined with the speed of data transfer between two nodes latency refers to the average time that elapses between a function call and data transfer itself. It is usually spent on addressing information, triggering intermediate network devices and other network situations arising during data transmission.

In general, we note that the capacity and latency not only characterize the work of the cluster, these characteristics also influence on restriction of the class of problems processed by using the cluster. So if the problem involves an intensive exchange of data sent packages having a small volume the cluster equipped with a network interface with a high-latency will spend a lot of time to establish a network connection, and less time to transfer data between nodes in the system. Under these conditions, the nodes in a multiprocessor system will be idle and parallelization efficiency will be significantly reduced. On the other hand, if data packets are large, the effect of latency on the system efficiency may be reduced due to the fact that the transmission takes considerably more time than the establishment of the connection. In this regard we consider the ramifications of choosing the network interface for the design of a modular multiprocessor system and following items describe each element of equipment and features of its functioning.

Network cables. For network management, diagnostics and loading we use the network technology *GigabitEtherne t* [7]. It introduces standard 1000*BASE-T*, *IEEE 802.3ab* which uses a twisted pair category 5e for communication. *InfiniBand* copper technology applicable in the switching network communication between slave-nodes of a multiprocessor system .

AC adapter. For this purpose, you can use network cards that supports the standards InfiniBand. In the design of the proposed multi-processor systems priority was given to the adapter company *Mellanox MHQH*29*C-XTR* [8]. Network cards from this company have significant affect on the performance of network communications. Each blade of the processor system includes four dual-port adapters (*IB*1 – *IB*4, Fig. 1). The main features of these adapters are: such adapters with support for the virtual protocol *VPI* (*Virtual Protocol Interconnect*) provide the most flexible and high-performance network connections for high-performance computing systems. Thanks to this multiprocessor system offers high performance, high-speed access to the network and storage resources, guaranteed bandwidth and low latency.

In addition, the adapter of *MHQH*29*C-XTR* type support data rates up to 10 Gbit / s per channel and may contain the serial control interface. Copper cable interface has the same performance as an optical one but has a lower price.

Switch. This is one of the most important devices of the network interface in a multiprocessor system which implements the aggregation and switching network channels. We use the 36-port switch *Grid Director* 4036 type of *Mellanox* (Voltaire) company with the capacity equal to 40 Gbit / s In the proposed multi-processor system.

This device relates to switches intended for the construction of high-performance multiprocessor systems based on copper compounds. They maintain a standard set of network technologies: in particular virtual network traffic prioritization, port trunk, multicast filtering, scaling to thousands of nodes and others.

Switch family manufacturer *Mellanox* for *InfiniBand* provides for superior performance and port density. It allows you to create the most cost-effective and scalable network commute ranging in size from small clusters to clusters having tens of thousands nodes. These switches can also transmit converged traffic by combining guaranteed bandwidth and great facilities of extended *QOS* which provides the highest system performance.

Technical network characteristics of the described system are shown in the Tabl. 1. The computational experiments to verify the performance of the system [9] were based on of this equipment.

Table 1. Technical characteristics of the network multiprocessor system

Network cable	Type	*InfiniBand*
	Capacity	10 Gbps
	Standard	IB QDR/FDR10 (40Gb/s), 4X QSFP
	Price, (1.0 м)	$ 84
	Price, (2.0 м)	$ 95
	Price, (3.0 м)	$109
Network	Type	*MHQH29C-XTR*
	Standard	*Mellanox*
	Capacity	10 Gbps
	Price	$ 818
Sswitch	Type	*Grid Director 4036*
	Standard	*Mellanox*
	Capacity	2880 Gbps
	Price	$ 8500

Star Topology. The main feature of this topology is that all processors in the system have a connection with the control processor. The structure of such a network is shown in Fig. 3.

At first the "distributed *VLANa* and *VLANb*" are configurated in the network switch *KIB*. In this case compute node *PM*001 is connected to an external first two-portal *HCA IB*1 via adapter input / output ports 1, 2 (*HCAm*001.1.1, *HCAm*001.1.2) and with the port *KIB*001 and *KIB*002 (*VLANa*) via the managed switch *KIB*, via the external second two-portal *HCA IB*2 adapter with the input / output ports 1, 2 (*HCAm*001.2.1, *HCAm*001.2.2), with ports *KIB*003 and *KIB*004 (*VLANa*) via the managed switch *KIB*, third two-portal *HCA IB*3 adaptera input / output ports 1, 2 (*HCAm*001.3.1, *HCAm*001.3.2) are connected with the port *KIB*005 and *KIB*006 (*VLANb*) with the managed switch *KIB* and by the fourth two-portal *HCA IB*4 adapter from input / output ports 1, 2 (*HCAm*001.4.1, *HCAm*001.4.2) with the port *KIB*007 and *KIB*008 (*VLANb*) via the managed switch *KIB*. According to this scheme the delivery of computing nodes in the cluster is connected. Network storage is attached to the switch *KIB* with four ports adapter *KIB*033, *KIB*034, *KIB*035, *KIB*036 with adapter *TCA*1, *TCA*2 to *VLANa* and adapter *TCA*3, *TCA*4 to *VLANb*. We obtain two virtually independent star topologies which increase the reliability and network speed of data exchange.

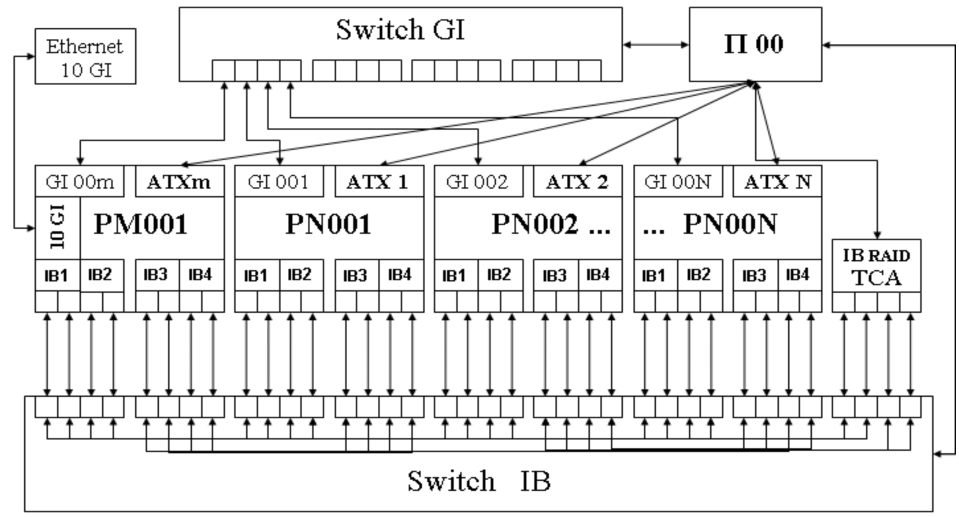

Fig.3. Structure of a network module of a multiprocessor system for implementing a star topology

Computational experiments. Features of development of parallel computational algorithms for the personal calculable cluster is in detail covered in [11]. The effectiveness of the proposed approach for the computational experiments confirmed the decision of problems of non stationary heat conduction, some aspects of inverse problems of modeling study of thermal properties of materials, the prediction problem of ecological systems under the influence of natural and anthropogenic factors. In addition, the developed multiprocessor system has been used for a more detailed calculation and for obtaining some new effects of the investigated processes. Parallel circuits for numerically analytical visualization of vectors' solutions are disclosed in [9]. The resulting isolines mark smoothness and the proposed approach makes it possible to build a minimum of work on the input and output data of the investigated class of problems. Furthermore, since the values of the basic grid nodes are arranged in region, the layer hour operation does not communicate with each other. Therefore, the calculations for constructing graphs or isolines can be executed in parallel and simultaneously.

Conclusions and prospects for future research. Introduction to the multiprocessor system having standard InfiniBand of a separate computer network for data exchange and implementation of mechanisms for aggregation network interface and support for *VLAN*, specially organized for the modes of data exchange in the network managed switch *KIB*, and developing a network boot mode processors and the redundancy the key components mechanism module enabled:

– firstly, to receive the following priorities through the application of InfiniBand technology: low latency, scalability, redundancy, the possibility of selecting the required velocity from a given speed range which in turn allowed to use the designed system to unleash to decouple the strongly coupled tasks and the tasks with the expanding field of computing ;

– second, to modify the configuration of the computer network adapting its structure to meet each specific type of tasks through a terminal or a *WEB*-interface;

– third, to execute the direct exchange of data between main memory nodes of a multiprocessor system due to the formation of a separate computer network with link aggregation and *VLAN* implementation mechanisms using application *RDMA* (*Remote Direct Memory Access*) technology and *InfiniBand* opportunity. It is possible to increase the speed of computation while unleashing tasks, provide high-speed access to the memory of the cluster nodes and data exchange between them, relieve the *CPU* for data exchange and reduce the bandwidth that extends between the nodes in the cluster;

– fourth, the use of adapters *ConnectX* provided new connective opportunities for different computing environments. This determines the increase in productivity throughout the computer system and allows to offload the *CPU* from the *InfiniBand* service traffic;

– fifth, to increase the effectiveness of the cluster system, adapting the structure of its network to the outbreak of the goals of each type;

– sixth, to simplify the design, build or replace the cluster nodes that are out of order, due to modularity, and also to simplify the work and operation of the entire system.

Prospects for further research in this scientific direction the authors see in the coverage of issues related with the study of computing in a multiprocessor system slow because of its expandable memory. There occurs the need for increased computing power of the system to decouple a certain class of applications. Founded principle of modularity can increase performance of the computer system through the addition of new slave-nodes. The authors consider it expedient to introduce the corresponding analytical expressions for calculating the efficiency of the claimed computer system. This would allow researchers to choose the most effective configuration of a multiprocessor system and its modes of operation. The authors intend to address such study in the next publications.

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Иващенко В.П., Швачич Г.Г., Холод Е.Г.

Некоторые аспекты конструирования высокоэффективной многопроцессорной системы

Аннотация. Работа посвящена проблеме моделирования архитектуры высокопроизводительных многопроцессорных систем обработки данных, которые используются при решении задач с расширяемой областью вычислений. Предложенная система характеризуется повышенной надежностью и высокой энергоэффективностью. Система содержит отдельную реконфигурируемую сеть для обмена данных между вычислительными узлами, управляемые коммутаторы, а также предусматривает сетевую загрузку узлов, механизм резервирования ключевых компонентов.

Ключевые слова*: многопроцессорная вычислительная система, управляемые коммутаторы, реконфигурируемая сеть, вычислительные узлы, буферы памяти, компоненты вычислительной системы*