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HIGH-PERFORMANCE MULTIPROCESSOR SYSTEMS IN SOLVING PROBLEMS WITH EXPANDING COMPUTING AREA

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

Keywords: *multiprocessor computer system; managed switches; reconfigurable network; compute nodes; memory buffers.*

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ВИСОКОЕФЕКТИВНА БАГАТОПРОЦЕСОРНА СИСТЕМА ДЛЯ РОЗВ'ЯЗУВАННЯ ЗАДАЧ ІЗ РОЗШИРЮВАНОЮ ОБЛАСТЮ ОБЧИСЛЕНЬ

У статті вирішено проблему моделювання архітектури високопродуктивних багатопроцесорних систем обробки даних, які використовуються при розв'язуванні задач з розширюваною областю обчислень. Запропонована система характеризується підвищеною надійністю і високою енергоефективністю. Система містить окрему реконфігуровану мережу для обміну даних між обчислювальними вузлами, керовані комутатори, а також передбачає мережеве завантаження вузлів та механізм резервування ключових компонентів.

Ключові слова: *багатопроцесорна обчислювальна система; керовані комутатори; реконфігурована мережа; обчислювальні вузли; буфери пам'яті.*

Рис. 3. Табл. 1. Літ. 11.

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ВЫСОКОЭФФЕКТИВНАЯ МНОГОПРОЦЕССОРНАЯ СИСТЕМА ДЛЯ РЕШЕНИЯ ЗАДАЧ С РАСШИРЯЕМОЙ ОБЛАСТЬЮ ВЫЧИСЛЕНИЙ

В сттаье решено проблему 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 и механизм резервирования ключевых компонентов.

Ключевые слова: *многопроцессорная вычислительная система; управляемые коммутаторы; реконфигурируемая сеть; вычислительные узлы; буферы памяти.*

Introduction. High-performance computing belongs to fundamental 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; and parallel execution of computational operations.

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The first method involves significant investments. 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 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 (Bakanov, 2006; Voevodin and Zhumatiy, 2007; Gergel and Strongin, 2003; Lacis, 2003). In this regard, one often identifies today the 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 a cluster; if financial resources are limited or the necessary computing power is known in advance it is easy to select the desired system configuration. Such systems emphasize theoretically unlimited scalability devices of this class.

The analysis of ways to develop high-performance systems shows that the real turning point in mastering parallel computing technologies can be achieved by developing additional (actually basic) level in the hierarchy of capacities of hardware multiprocessor computing systems *MPP*-architecture or personal computing clusters. Thus, it is proposed to establish the foundation of the pyramid hardware technology for parallel computing as personal computing clustersm 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 their widespread use as well mastering techniques of parallel computing is only possible as a result of widespread use of *PCs*. In this case, if the beginning of the common use of PCs belongs to the second half of the 1980s, the middle of the first decade of the 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 model developed software.

This paper shows that the problems that arise when developing parallel computing systems usually are paramount and require indepth study and research. Indeed, a distributed (parallel) computer modelling covers the entire spectrum of modern computing: supercomputers, cluster computing systems, local and wide area networks etc. In addition, distributed modelling permits solving problems which 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.

Problem statement. The work is dedicated to modelling 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 a difference grid dimension *M*; time of computing a problem by using a single-processor system is determined by the value *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 a multiprocessor 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 reconfigurated network for data exchange 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.

Recent research and publications analysis. In today's conditions cluster systems are constructed using 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 the 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. The 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 etc.

There are many computing systems with the shared memory which are oriented on solving 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 (www.beowulf.org).

Nevertheless, we should be note the following disadvantages of a multiprocessor system:

1. Low real productivity solutions of strongly coupled tasks. This disadvantage arises 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. High costs of the system. It is predetermined by application of 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 for this is the need for high energy consumption by infrastructure of the entire cluster system (*8 kVA, 10 kVA*),which increases the cost of holding the cluster. To create conditions for reliable operations of the cluster we need to reserve the necessary components to form a cluster, and this, in turn, increases the costs of operating a cluster system.

4. Complexity of cluster operations. 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 parallel computations significantly depends on many factors, one of the most important is the specificity of 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 modelling a wide class of problems with the help of modular multiprocessor systems and today these are being addressed by many researchers (Lacis, 2003; Blackford MultiCore; Beowulf Introduction & Overview).

In practice of parallel computing the known module of a high effective multiprocessor system on high alert contains (Patent # 61944, 2011) one master node (*MNode001*) and 5 slave-computing nodes (*NNode001, NNode002, NNode003, NNode004, NNode005*), 3 controlled switch (*SW1, SW2, SW3*), intermediate buffer memory switches, reconfigurated network for data exchange between computing nodes, virtual *LANs*, the redundancy mechanism of key components, and also network booting nodes. Commutative network of multiprocessor computing system operates in two modes: having topology of the star type or of the circle one. This cluster system is based on the 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 components of the control equipment in the 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 is paid to the possibility of extension or modification of the cluster in the future.

Among the disadvantages of such a system we can mention:

1. Inability to use the system for solving problems with expandable calculations area. This disadvantage is predetermined by the fact that communication environment for all nodes of a cluster system is designed to use one-gigabit network. In solving the problems with expandable area calculations we will meet the overload of network resources of the system so as the processors will be forced to idle and the system will work only on 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 on 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 deployment of two modes. The first mode simulates the 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 the expansion of a cluster system the number of its blades will be limited because of an overload of network resources.

Unresolved issues. The existing multiprocessor computing systems are not focused on solving tasks with an expanding field of computing. The current methods of analyzing the effectiveness of multiprocessor systems do not allow determining 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 network interface on the efficiency of such systems have not been performed yet. In addition, for evaluating the effectiveness of a computer system the basic analytical relations through the parameters of the studied system are not yet determined.

The purpose of the study is to provide a multimodule computer system, the real efficiency and productivity of which would peak at solution of strongly coupled problems and problems with an expanding field of computing. In addition, such a system must have a 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 designing the claimed system in universities, research organizations, research centers etc. Due to the significant demand for blade configuration systems at the domestic market further development of blade technology for the construction of the cluster computing system is of a great interest.

Key research findings. ***Design features of the multiprocessor system.*** Multiprocessor module system includes one master node (*PM001*) and slave-computing nodes (*PN001, PN002, PN003, ..., PN00N*), 2 controlled switches (*KGI, KIB*), intermediate buffer memory switch *KGI*, reconfigurated network for communication between computing nodes, *VLANs* core redundancy components and also a network boot nodes. Commutative multiprocessor computing system operates in 6 modes: star, circle, ruler, complete graph, grid and lattice closed. These modes are focused on the implementation of the limited data exchange representing particular problems which are to be solved using the proposed system. Figure 1 shows its block diagram.

As a model we chose a single unit which represents a computing cell enclosure. Thus, if necessary, several units can be placed in a single housing; on the other hand, such an approach provides a compact, successful cooling and easy access to sockets and other elements of the target board. The computing system includes a vertical arrangement of motherboards, parallel to each other, corresponds to the idea of *"Blade"* servers.

After the OS downloading the access to the multiprocessor system can be obtained from the standard network protocols (*telnet, ssh, rsh*), as in the case with a usual PC. In this case, for the organization of a supercomputer based on the working PC and multiprocessor system we require only a network connection between them which can be arranged with the help of topology "point-to-point". Possible communication modes for the desktop *PC* with the multiprocessor system is shown in Figure 2.

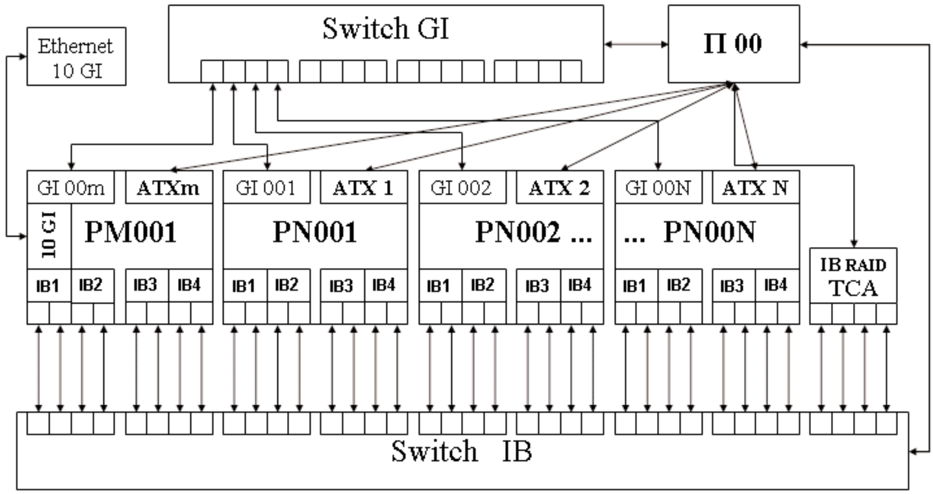

Figure 1. **Block diagram of the multiprocessor system,** *authors' development*

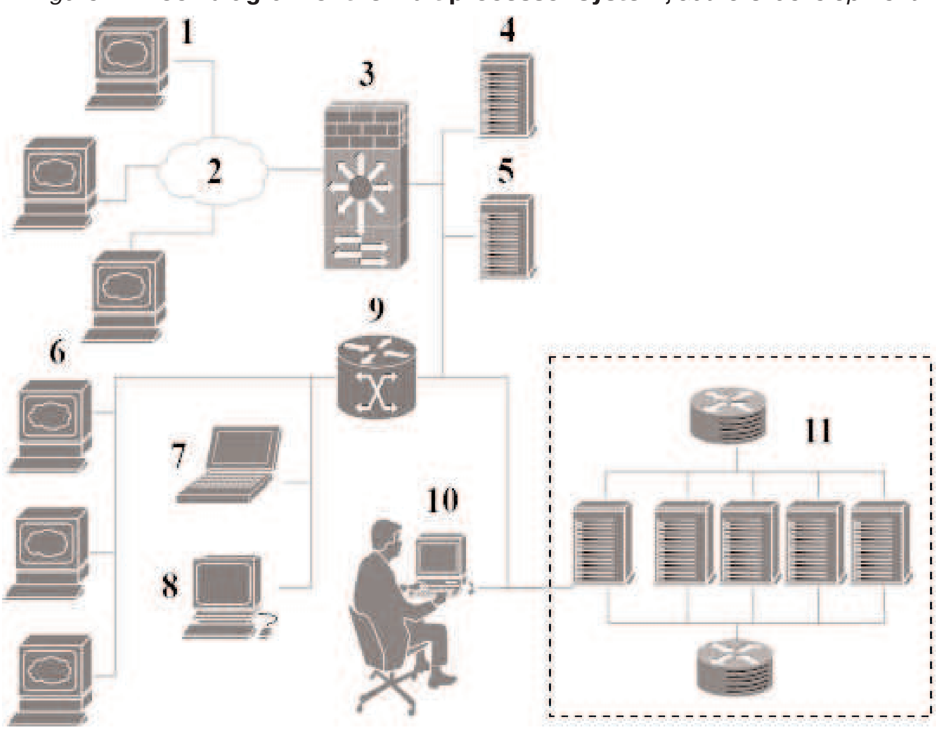

Figure 2. **Communication modes desktop PC with the multiprocessor system,** *authors' development*

Distant access to the system resources 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 system resources is ensured through multistationary station working groups and laboratories of a university (6), personal mobile laptop station (7), experimental laboratory (8) and through personal workstation operator of the multiprocessor system (10).

Features of module's functioning 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 call for the startup and initialization of the master node module system. Loading of operating system directly can be performed either from a hard disk or from *CD/DVD*. 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 at 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 (*ATX1—ATXN*) and initialization of slave-nodes reduces the required power for unit *UPS*, runs all computing nodes and slave-load operating systems in them. After downloading and debugging all computing nodes of the cluster the appropriate script is finalized and the system is ready to perform parallel computations.

Master node (*PM001*) through the switch *KGI* provides the direction of data related to management, diagnosis and downloading of tasks' conditions. In turn, the slave-nodes respectively to the solving algorithm, implement the mode of computation required. Data exchange 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 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 *HCA (host channel adapters)*. Directing data storage for further processing is performed via the *TCA (target channel adapters)*.

Functioning features of a module multiprocessor computer system. At the first stage of the research we consider how to build the interface and what are its main operation modes. For convenience we assume that the computer network system has two main characteristics: bandwidth and latency. The capacity of the computer network is defined by 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 understand that capacity and latency not only characterize the work of the cluster, these characteristics also influence the restriction of the class of problems processed by using the cluster. So, if the problem involves 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 establishing a network connection, and less time on data transfer between nodes in the system. Under these conditions, 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 transmission takes considerably more time than the establishment of connection. In this regard we consider the ramifications of choosing the network interface for designing 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* (grouper.ieee.org). It introduces standard *1000BASE-T, IEEE 802.3ab* which uses the twisted pair category 5e for communication. *InfiniBand* copper technology is applicable in the switching network communication between slave-nodes of a multiprocessor system.

AC adapter. For this purpose, we can use network cards that support the standards of InfiniBand. In the design of the proposed multi-processor systems priority is given to the adapter company *Mellanox MHQH29C-XTR* (Mellanox Technologies). Network cards by this company have significant affect on the performance of network communications. Each blade of the processor system includes 4 dual-port adapters (*IB1–IB4*, Figure 1). The key features of these adapters are: they support the virtual protocol *VPI (Virtual Protocol Interconnect)* providing the most flexible and high-performance network connections for high-performance computing systems. Thanks to this, the multiprocessor system offers high performance, high-speed access to network and storage resources, guaranting bandwidth and low latency.

In addition, the adapter of *MHQH29C-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 usyally is of 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 creating 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* providing the highest system performance.

Technical network characteristics of the described system are shown in Table 1. The computational experiments to verify the performance of the system (Ivashchenko et al., 2014) were based on of this equipment.

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 Figure 3.

At first the "distributed *VLANa* and *VLANb*" are configurated in the network switch *KIB*. In this case compute node *PM001* is connected to the external first two-portal *HCA IB1* via adapter input/output ports 1, 2 *(HCAm001.1.1, HCAm001.1.2*) and with the port *KIB001* and *KIB002* (*VLANa*) via the managed switch *KIB*, via the external second two-portal *HCA IB2* adapter with the input/output ports 1, 2

(*HCAm001.2.1, HCAm001.2.2*), with ports *KIB003* and *KIB004* (*VLANa*) via the managed switch *KIB*, third two-portal *HCA IB3* adaptera input/output ports 1, 2 (*HCAm001.3.1, HCAm001.3.2*) are connected with the port *KIB005* and *KIB006* (*VLANb*) with the managed switch *KIB* and by the fourth two-portal *HCA IB4* adapter from input/output ports 1, 2 (*HCAm001.4.1, HCAm001.4.*2) with the port *KIB007* and *KIB008* (*VLANb*) via the managed switch *KIB*. According to this scheme, the connection of computing nodes in the cluster is performed. Network storage is attached to the switch *KIB* with 4 ports adapter *KIB033, KIB034, KIB035, KIB036* with adapter *TCA1, TCA2* to *VLANa* and adapter *TCA3, TCA4* to *VLANb*. We obtain two virtually independent star topologies which increase the reliability and network speed of data exchange.

Table 1. **Technical characteristics of the network multiprocessor system,** *authors' development*

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

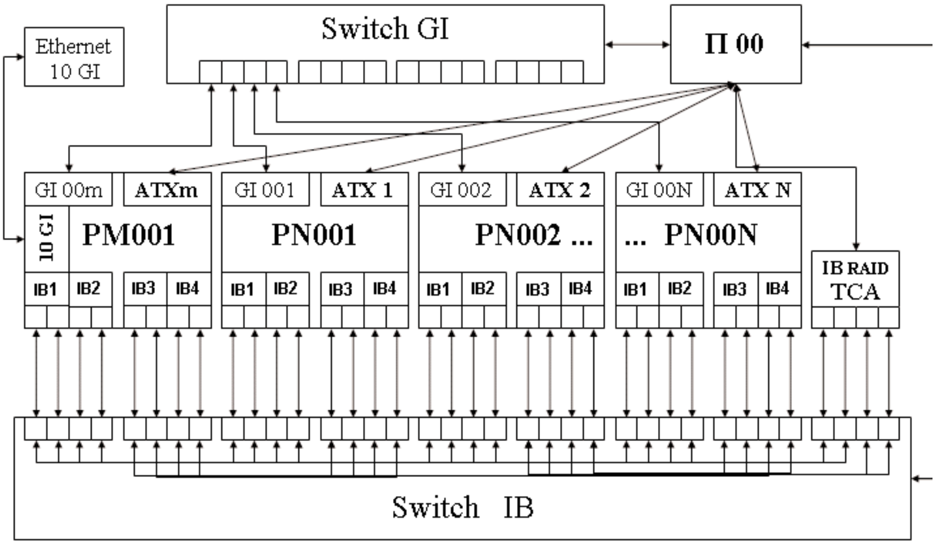

Figure 3. **Structure of a network module of a multiprocessor system for implementing a star topology,** *authors' development*

Computational experiments. Development features of parallel computational algorithms for the personal calculable cluster are covered in detail in (Shvachych and Shmukin, 2004). The effectiveness of the proposed approach for computational experiments confirmed the decision of problems of non stationary heat conduction, some aspects of inverse problems of modelling 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 more detailed calculations and for obtaining some new effects of the investigated processes. Parallel circuits for numerically analytical visualization of vectors' solutions are presented in (Ivashchenko et al., 2014). The resulting isolines mark smoothness and the proposed approach makes it possible to build a minimum of work on input and output data of the investigated class of problems. Furthermore, since the values of the basic grid nodes are arranged in a certain scope, the layer operations do 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 InfiniBand standard 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 of the key components mechanism module enabled:

- firstly, receiving 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 using the designed system to decouple the strongly coupled tasks and the tasks with the expanding field of computing;
- second, modifying the configuration of the computer network adapting its structure to meet each specific type of tasks through a terminal or a *WEB*-interface;
- third, executing 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 computation speed while unleashing tasks, provide high-speed access to the memory of cluster nodes and data exchange between them, relieve the *CPU* for data exchange and reduce the bandwidth which 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 offloading the *CPU* from the *InfiniBand* service traffic;
- fifth, increasing the effectiveness of the cluster system, adapting the structure of its network to the outbreak of the goals of each type;
- sixth, simplifying the design, building or replacing the cluster nodes that are out of order, due to modularity, and also simplifying the operations of the entire system.

Prospects for further research in this scientific direction the authors see in coverage of the issues related to studying computing in a multiprocessor system and its expandable memory. Here there is a need for increased computing power of the system to decouple a certain class of applications. The principle of modularity can increase the performance of the computer system through 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 choose the most effective configuration of a multiprocessor system and its operation modes. The authors intend to address this issue in their next publications.

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