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ИНФОРМАЦИОННЫЕ И ТЕЛЕКОММУНИКАЦИОННЫЕ ТЕХНОЛОГИИ

UDC 004.75

A.R. AKHATOV, A. RENAIVAR, A.E. RASHIDOV, F.M. NAZAROV

DEVELOPMENT OF THE BIG DATA PROCESSING ARCHITECTURE BASED ON DISTRIBUTED COMPUTING SYSTEMS

Today, the growth of the flow of digital data requires unusual, specialized methods and tools for storing and processing it. The storage and processing of large volumes of data using a conventional single computing system are not efficient, neither in terms of storage nor processing speed. With that in mind, storing and processing large amounts of data using interconnected computing systems can have a number of benefits. One of the main tasks in the joint use of these computing systems is the correct choice of the scheme of interaction between them, as well as the software architecture. This research presents the efficiency and high-efficiency approach to storing and processing Big Data's Fast Data and Big Analytics class data using distributed computing systems. In addition, this research analyzes the

requirements for distributed computing systems in Big Data processing and storage, as well as the interconnection schemes and software architectures of distributed computing systems for Big Data processing and storage. As a result of this research, an optimized architecture for the Big Data processing and storage of a distributed computing system was developed.

Keywords. Big Data, Fast Data, Big Analytics, Deep Insight, Amdahl's law, Gustafson's law, interconnection scheme of a distributed computing system, distributed software architecture, optimized distributed computing system architecture.

A.R. Akhatov, A. Renavikar, A.E. Rashidov, F.M. Nazarov

Taqsimlangan hisoblash tizimlariga asoslangan katta ma'lumotlarni qayta ishlash arxitekturasini ishlab chiqish

Hozirgi vaqtda raqamli ma'lumotlar oqimining oshib borishi ularni saqlash va qayta ishlashda noodatiy, maxsus usul va vositalarni talab qilmoda. Odatdagi yagona hisoblash tizimi yordamida katta hajimdagi ma'lumotlarni saqlash va qayta ishlash, ham saqlash jihatidan, ham qayta ishlash tezligi jihatidan samarali emas. Buni hisobga olib aytadigan bo'lsa, katta hajmdagi ma'lumotlarni saqlash va qayta ishlashni bir biri bilan o'zaro hamkorlikda ishlay oladigan hisoblash tizimlari yordamida amalga oshirish bir qancha samaradorliklarga olib keladi. Ushbu hisoblash tizimlarini hamkorlikda ishlatishda ular orasidagi o'zaro bog'lanish sxemasini, hamda dasturiy ta'minot arxitekturasini to'g'ri tanlash asosiy vazifalardan biri hisoblanadi. Mazkur tadqiqot ishida Big Dataning Fast Data va Big Analytics sinfi ma'lumotlarini taqsimlangan hisoblash tizimlari yordamida saqlash va qayta ishlash samaradorlik ko'rsatgichlari va yuqori samaradorlikka erishish yondashuvi keltirilgan. Bundan tashqari ushbu tadqiqot ishida Big Datani qayta ishlash va saqlashda taqsimlangan hisoblash tizimlariga qo'yiladigan talablar, hamda Big Datani qayta ishlash va saqlash uchun taqsimlangan hisoblash tizimining o'zaro bog'lanish sxemalari va dasturiy ta'minot arxitekturalari tahlil qilingan. Ushbu tadqiqot natijasi sifatida taqsimlangan hisoblash tizimining Big Datani qayta ishlash va saqlash uchun optimallashtirilgan arxitekturasi ishlab chiqilgan.

Kalit so'zlar. Big Data, Fast Data, Big Analytics, Deep Insight, Amdahl qonuni, Gustafson qonuni, taqsimlangan hisoblash tizimining o'zaro bog'lanish sxemasi, taqsimlangan dasturiy ta'minot arxitekturasi, taqsimlangan hisoblash tizimining optimallashtirilgan arxitekturasi.

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Разработ ка архит ект уры обработ ки больших данных на основе распределенных вычислит ельных сист ем

Показано, что ныне рост потока цифровых данных требует необычных, специализированных методов и инструментов для их хранения и обработки. Хранение и обработка больших объемов данных с использованием обычной единой вычислительной системы неэффективны ни с точки зрения хранения, ни с точки зрения скорости обработки. Имея это в виду, хранение и обработка больших объемов данных с использованием взаимосвязанных вычислительных систем может иметь ряд преимуществ. Одной из основных задач при совместном использовании этих вычислительных систем является правильный выбор схемы взаимодействия между ними, а также архитектуры программного обеспечения. В этом исследовании представлен эффективный и высокопроизводительный подход к хранению и обработке больших данных класса Fast Data и Big Analytics с использованием распределенных вычислительных систем. Кроме того, в этом исследовании анализируются требования к распределенным вычислительным системам в области обработки и хранения больших данных, а также схемы взаимосвязей и программные архитектуры распределенных вычислительных систем для обработки и хранения больших данных. В результате исследования была разработана оптимизированная архитектура обработки и хранения больших данных распределенной вычислительной системы.

Ключевые слова: большие данные, Fast Data, Big Analytics, Deep Insight, закон Амдала, закон Густафсона, схема взаимосвязи распределенной вычислительной системы, распределенная архитектура программного обеспечения, оптимизированная архитектура распределенной вычислительной системы.

Introduction. At present, with the digitization of data and decision-making based on this information, the organization of management is drastically implemented in all areas. As a result, humanity has to deal with a huge variety of data streams called Big Data. Although the concept of Big Data has not been around for a long time, there is a lot of research being done by scientists around the world on related topics. Because the effective use of Big Data, that is, its complete and accurate analysis, increases the reliability of data and opens up great opportunities for people to make the right decisions in all areas [1].

In practice, research to date has focused on two main aspects of Big Data research: [2].

- Improving the efficiency of Big Data storage and processing architecture;

- Use Big Data in specific areas.

Of course, the results of the first research direction will affect the results of the second research. The main approach that needs to be addressed first in increasing the efficiency of Big Data processing architecture is to focus on the size and diversity characteristics of the Big Data being studied. This will help Big Data choose the most convenient of the architectures proposed by many researchers or develop a new approach. However, most studies do not emphasize the exact limits of the size property of Big Data, and only a few studies have discussed this [3–4]. One such researcher, Hinchcliff, divides approaches to Big Data into three classes according to size. They are followings [5]:

- Fast Data, measured in terabytes;
- Big Analytics, petabytes data;
- Deep Insight, zettabytes data.

Today, the third class of Big Data is practiced by only a handful of organizations and companies around the world. Most people are confronted with the Fast Data and Big Analytics classes, which are relatively small in size compared to the Big Data classes. Although small in size compared to the third class, the processing of data from this class also requires special methods and tools. Because they are also different sets of data that cannot be received, managed, and processed in a short period of time by software and hardware of Big Data and traditional information technologies [6]. Therefore, it is important to develop and improve the mechanisms of data processing of these two classes. Given the large size of the data and the low capacity of processing it in a single computing system, the most effective approach is to process the data using distributed computing mechanisms.

Distributed computing system. Because Big Data is a large stream of data with a variety of properties, processing it through a single computing system is not very efficient [7]. Therefore, it is much more efficient to store and process such data streams using multiple computing systems. These computing systems are required to collaborate in the Big Data processing process. Typically, systems consisting of a combination of such servers and or computers are called distributed computing systems.

A distributed computing system is a set of computers that do not have a common memory or a common physical clock, communicate through messages over a communication network, and each computer has its own memory and runs on its own operating system [8].

The main requirement for distributed computing systems in the Big Data processing process is to achieve their transparency, openness, and scalability [9]. A distributed system should hide differences in how data is presented and access to resources. This feature of distributed systems is called data access transparency. Openness is the use of syntactic and semantic rules based on standards. For a distributed system, this is primarily the use of formalized protocols. Distributed software systems have scalability that can manifest itself in terms of size, geographic location, and administrative structure of the systems. Achieving scalability involves solving problems in services (single server for multiple clients), data (multiple access to the same data file), and algorithms (overloading the connection due to the use of centralized algorithms).

The distributed system has a unique potential to provide high reliability due to the ability to duplicate and implement resources [10]. Reliability includes several aspects:

- availability, ie the resource must always be available;
- integrity, ie the value or status of a resource must be compatible with multiple processors at the same time;
- fault tolerance, ie the ability to repair system faults.

Big Data processing efficiency indicator of distributed computing systems. Distributed computing is a method used to increase the scale of parallel code execution using a communication network [11]. Distributed computing is not always used for parallelism, but it is advisable to use parallel programming to increase the efficiency of Big Data processing. Several concepts have been identified to demonstrate the efficiency of parallel processing in Big Data distributed systems. These concepts include acceleration, cost-effectiveness, and scalability, which describe

performance improvements in terms of time savings, and how well an algorithm or piece of hardware works when more processors are added. Of these, the best way to determine efficiency is to accelerate.

Speedup is a controversial concept that can be defined in a variety of ways. In general, the speedup is defined as the ratio of the time required to solve a problem in a single processor to the time required by the N processor [12]. However, this rule shows that as the number of processors increases, so does the speed until the saturation point is reached. After this point, adding additional processors will not increase the additional efficiency. This effect implies a parallel performance limit in distributed computing systems: when the number of processors reaches a certain limit, the addition of additional processors no longer leads to further performance improvements. Sometimes the subsequent redistribution of tasks and the additional costs of inter-process communication and duplicate computing can even lead to a decrease in productivity. Gen Amdahl provides a very simple analysis on this [13], later called Amdahl's law. Amdahl gave the speedup of the parallel program in distributed systems as follows:

$$S(N) = \frac{T(1)}{T(N)} = \frac{T(1)}{(s + \frac{p}{N}) \cdot T(1)} = \frac{1}{s + \frac{p}{N}}$$

Where S(N) is the speedup achieved with N processors, T(1) is the time required to complete the work for a single processor, T(N) is the time required for N processors, p - parallel in a distributed computing system the share of work done and $s = 1 - p$ - the share of work done in series. According to this formula, the processor dependence of the distributed computing system acceleration is the same as shown in table 1 and fig. 1.

Table 1

The dependence of the speedup of a distributed computing system on the processors at $p=0.7$ and $s=1-0.7=0.3$

N	1	3	5	7	9	11	13	15	17	19	21	...	100
S(N)	1	1.875	2.272	2.5	2.647	2.75	2.826	2.884	2.931	2.968	3	...	3.257

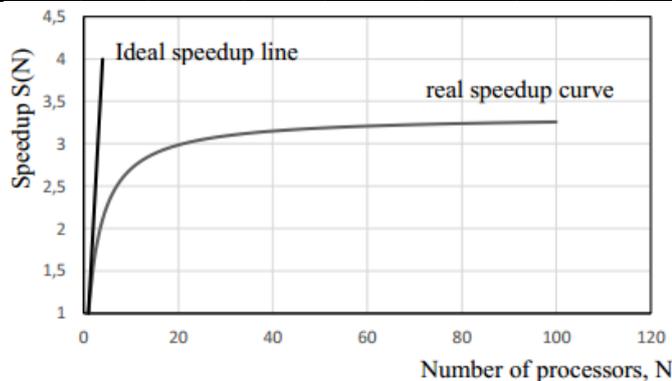


Fig.1. Graph of the dependence of the speedup of a distributed computing system on the processors at $p=0.7$ and $s=1-0.7=0.3$

Based on the real speedup curve shown in Figure1, it can be observed that with the increase in the number of processors, the efficiency increases very little, significantly. Amdahl's law led to a pessimistic view of parallel processing in distributed computing systems. Since 1967, Amdahl's law has been used as an argument against parallel processing in distributed computing systems.

However, given the size of the data and the efficiency of the data processing hardware and software at the time, it is possible to change this pessimistic view. Because today's technology and methods allow you to increase the amount of parallel work in the processing of large amounts of data and even bring it closer to 1. With this in mind, if we increase the share of parallel operation to $p=0.99$, we can see that the speedup rate also increases in proportion to the number of processors (Fig. 2). It is true that in this case,

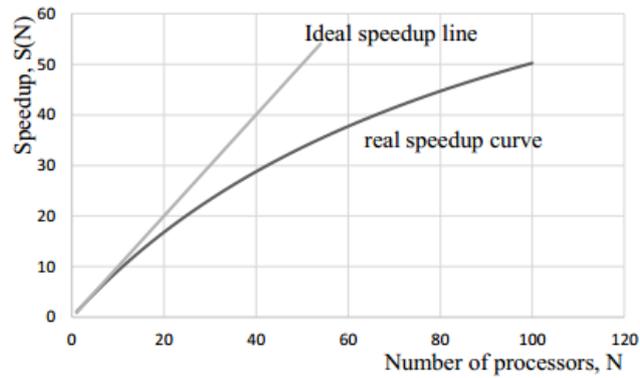


Fig. 2. Graph of the dependence of the speedup of a distributed computing system on the processors at $p=0.99$ and $s=1-0.99=0.01$

when the number of processors is 100, the real speedup curve is not far from the ideal acceleration curve, but in this case, too, the efficiency begins to decline after the number of processors begins to exceed 100. But the collaboration of 100 processors to process Fast Data and Big Analytics data gives good results.

In general, Amdahl's law is a rough way of estimating how effective a parallel calculation can be for a given problem. This is because having more processors in a distributed computing system allows you to increase the size of the problem to achieve higher results [14]. Gustafson's theory of the emptiness of Amdahl's law is also proof of this. According to Gustafson's observations, the amount of work that can be done in parallel varies linearly depending on the number of processors, and the amount of work in series, mainly with vector startup, program loading, series barriers, and input-output, problem size does not grow [15]. s' and p' should be used to indicate the execution time associated with serial code and parallel code, rather than the ratio of work expended on n parallel processors with the same processor. If this task is to be performed on a single processor, the required time can be expressed as:

$$T(1) = s' + p' .$$

The speedup can be written as the followings:

$$S'(N) = \frac{T(1)}{T(N)} = \frac{s' + Np'}{s' + p'} = N - (N-1) * \frac{s'}{s' + p'} = N - (N-1) * s'' .$$

Here $s'' = \frac{s'}{s' + p'}$ is the ratio of serial workload time to total time. According to Gustafson's

law, the speedup can be linearly increased by the number of processors in a distributed computing system. This can also be seen from the graph shown in Fig. 3.

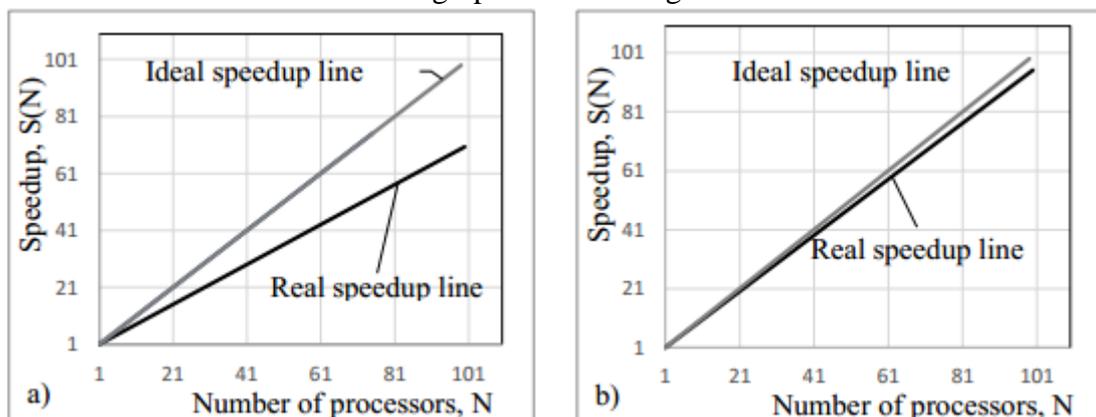


Fig. 3. Graph of the dependence of distributed computing system speedup on processors based on Gustafson's law:

a – here $p'=0,7$ and $s'=1-0,7=0,3$; **b** – here $p'=0,95$ and $s'=1-0,95=0,05$

Gustafson's law has more meaning than Amdahl's law. Because with large distributed computing power, it is desirable to process data and achieve better results in terms of high accuracy in many digital applications. When the scope of the problem was determined, Amdahl's law said to reduce the part of the code that had to be executed sequentially. In fact, we need to reduce the amount of code that can't be executed by introducing more processors.

Based on Amdahl's and Gustafson's laws, the use of a distributed computing system involving multiple processors in Big Data processing is effective.

Selection of the interconnection scheme of a distributed computing system for Big Data processing. Another important factor that is closely related to the efficiency of a distributed computing system is inter-process communication and synchronization. In particular, the transmission of large amounts of data from one server to another without collisions and losses is a difficult part of system efficiency. This also affects the parallel processing process in distributed systems. Therefore, the choice of a distributed computing system interconnection scheme for Big Data processing affects work efficiency.

There are several interconnection schemes for distributed computing systems, the main of which are shown in Fig. 4 [14].

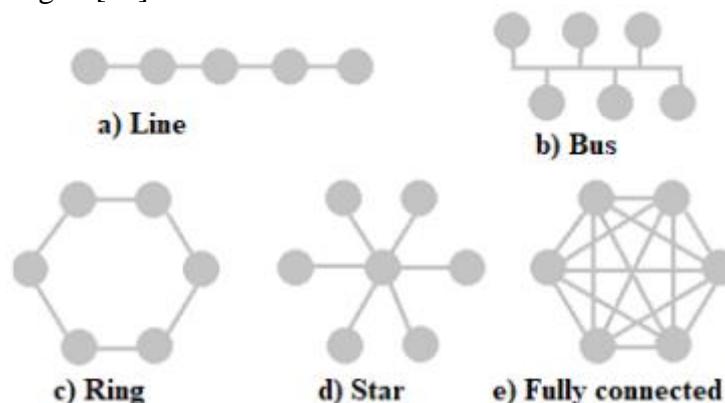


Fig. 4. Simple interconnection diagrams of distributed computing systems. In this figure, the circle represents the compute node, and the line represents the direct communication channel between the nodes

Linear interconnection scheme - computational nodes are placed and connected on a single line (Fig. 4, *a*). Routing is simple and topology can be seen as recursive. However, the connection between any two non-adjacent nodes needs the help of other nodes, and failure at any intermediate node will disrupt the entire system. In summary, this scheme is simple and inexpensive but does not create high performance or reliability for Big Data processing, and productivity decreases rapidly as the system scale increases.

The bus has a direct connection between any two nodes in the interconnection scheme (Fig. 4, *b*). The interconnection is via a common bus. This significantly reduces the complexity of the connections. However, given the large amount of data flowing through the bus, each subscriber spends a lot of time on the communication channel. As a result, messages sent at the same time do not reach their destination due to a collision.

A ring interconnection scheme is an improved circuit with an additional connection between the two ends of a linear interconnection scheme (Fig. 4, *c*). This reduces the connection distance by 2 times. However, the basic features are still the same, Big Data cannot generate high performance or reliability for processing, and productivity decreases rapidly as the system scale increases.

The star interconnection scheme has a central subscriber that connects all subscribers (Fig. 4, *d*). Since each communication channel serves only two subscribers, there is no data conflict. In addition, the interconnection distance is 2, which supports the easy implementation of collective communication with the help of a central switching node and allows recursive expansion. However, due to a large amount of data, the large number of tasks for processing and

synchronization between subscribers, the central computer is constantly overloaded, and any malfunction of the central computer loses the connection. This will damage the reliability of Big Data processing.

Fully interconnected scheme. It has a direct connection between any two compute nodes (Fig. 5, *e*). The interconnection distance is 1, and each communication channel connects only two compute nodes. As a result, these increase the reliability of Big Data processing.

In short, a fully interconnected interconnection scheme results in the highest possible efficiency and reliability. But this scheme also has some shortcomings. Too many nodes can lead to complications in the relationship. But this scheme is the most effective interconnection scheme for fast data and big analysis.

Selection of a distributed software architecture to process Big Data. There are 4 main types of distributed software architecture, which differ in the number of layers they include: single, double, triple, and multi-level architectures [9].

Single-layer architectures operate as all three layers (presentation, program, and resource) are parts of a single program (located at the same level) and a simple terminal client. Single-tier systems are difficult and expensive to maintain. It is therefore difficult to process Big Data using this architecture.

Two-layers architectures are very popular in the form of client-server architecture. Two-tier systems are much more mobile, meaning that the server is separated from the presentation layer, and the presentation layer is in the client. Combining application logic and resource management allows you to perform important calculations very quickly. One of the main problems with a two-tier architecture is that the server has limited ability to communicate with multiple clients at the same time. This, in turn, limits the use of Big Data processing from a two-tier architecture.

In a three-layer architecture, there is an intermediate system support layer between the presentation layer and the resource management layer (Figure 5). The advantages of a three-layers architecture are especially evident when combining different resources. Modern mid-range software includes the functions needed to add additional features to these layers: transaction guarantees for different types of resources, hardware load balancing, event recording capabilities, replication, data continuity, and others. Performance losses are offset by the distribution of the middle layer model to different network nodes, which significantly affects the scale and reliability of the systems. The limitations of the three-layers system architecture manifest themselves poorly when trying to combine several three-layers systems, as well as when distributed systems enter the Internet layer, which is due to the fact that these systems are not sufficiently standardized.

Multi-layers architectures are not much different from three-layers architectures: they are a generalization of the three-layers model, given the importance of accessing data over the Internet. Multi-layers architectures are designed for two main applications: connecting different systems and connecting to the Internet. The individual layers of a multi-level architecture are themselves two- or three-level systems.

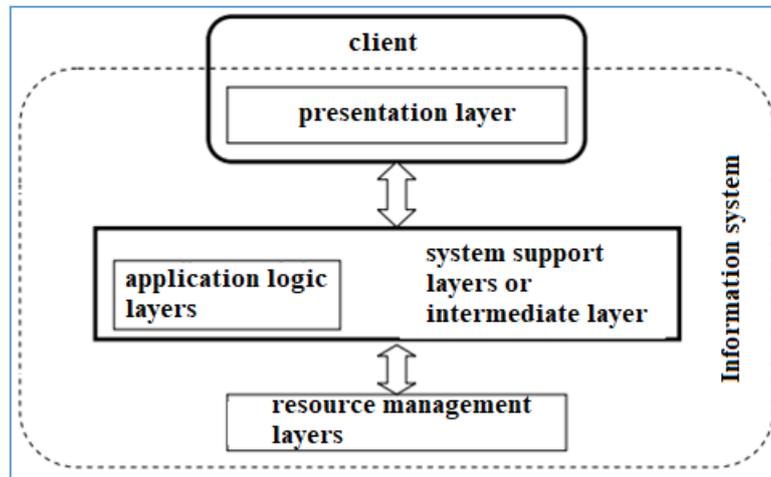


Fig. 5. In a three-layers architecture, there is an intermediate system support layer between the presentation layer and the resource management layer

From the above, it can be concluded that it is more efficient to choose a three-layers architecture from distributed software architectures to process large volumes of data with different characteristics. But given that the Big Data source can be accessed by the majority of users over the Internet, multi-layer architectures can be said to be the most convenient architecture for data processing and reliability.

The architecture of distributed computing systems designed to process Big Data. As mentioned above, processing Big Data using distributed computing systems offers a number of opportunities, such as increased efficiency and reliability of data processing. But the right choice of distributed system interconnection scheme and distributed software architecture will further enhance these capabilities. In light of the views and considerations discussed above, in this study, we propose an architecture for processing Big Data using distributed computing systems Fig. 6.

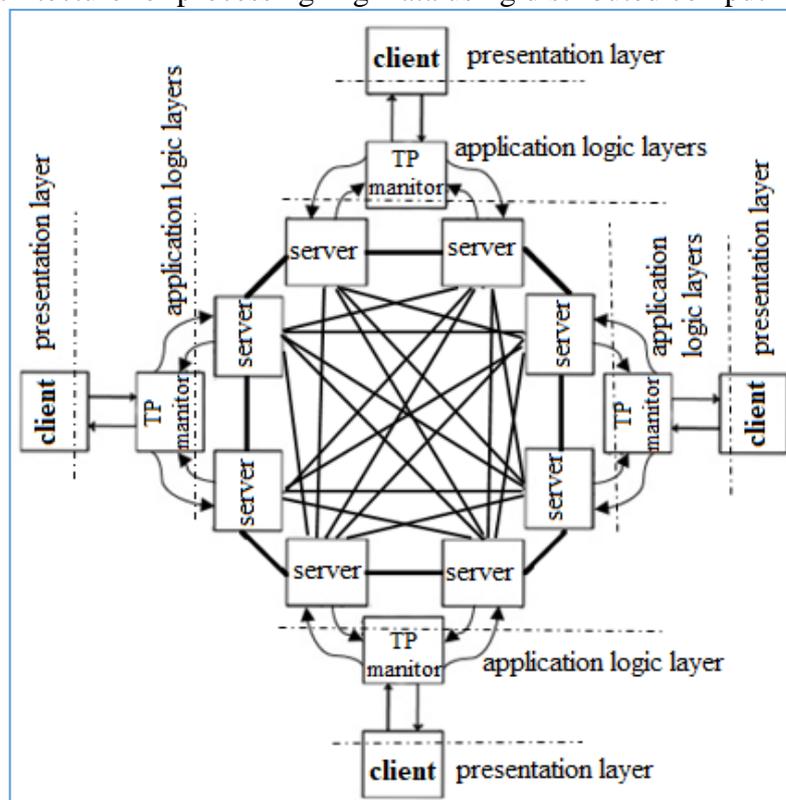


Fig. 6. Architecture of distributed computing systems for Big Data processing

In this architecture, computing systems are interconnected using a fully interconnected circuit. This maximizes the interaction between computing systems and prevents data collisions. In addition, the presence of a communication channel between each computer system, which gives the system the ability to hide the failure of any subscriber (server). As a result, data processing is more reliable.

In addition, the multi-layer architecture selected for the distributed computing system allows the integration of different resources, transaction guarantees for different types of resources, hardware load balancing, event logging, data copying, data continuity, internet connection and more.

Conclusion. In this research, the mechanism for storing and processing Big Data using distributed computing systems was considered. Features and capabilities of a distributed computing system are studied. Based on Amdahl's and Gustafson's laws, the parallel processing capabilities of a Big Data data distributed computing system are mentioned, and the efficiency of a distributed computing system based on experiments is shown. In a distributed computing system, the interconnection schemes between the computing systems were analyzed, and the scheme that was most efficient for Big Data processing was selected from the analyzed interconnection schemes. The software architectures of the distributed computing system were considered, and the software architecture for processing Big Data data was selected from them. At the end of the research, the Big Data Processing Architecture for a distributed computing system based on what was studied during the research is presented.

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**ТАСВИРДА ТУРЛИ ТЕКИСЛИК БУРЧАГИ ОСТИДА ЖОЙЛАШГАН ЮЗ
СОҲАЛАРИНИ АНИҚЛАШ**

Мақолада тасвирдаги турли текислик бурчакларида акс этган юз тасвирларини аниқловчи босқичма-босқич созлаш нейрон тармоқ модели таклиф этилган. Модел учта прогрессив босқичдан иборат бўлиб, ҳар бир босқичда кам эҳтимолликдаги номзодлар (юз тасвирлари) ўчирилади, юз тасвирлари чегараловчи рамкалар регрессияси қайтарилади ва уларнинг текисликда айланиш

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