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Shafagat Mahmudova
Institute of Information Technology, B. Vahabzade Str., 9A, AZ1141 Baku, Azerbaijan

Corresponding Author:
Shafagat Mahmudova
Institute of Information Technology, B. Vahabzade Str., 9A, AZ1141 Baku, Azerbaijan

Development of a method for increasing the reliability of distributed software systems on cloud systems platform

Shafagat Mahmudova

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Abstract
Cloud computing allows users to store and manage data efficiently. This research aims to develop a method for creating of distributed software systems on the platform of cloud systems and improving their reliability. The use of cloud computing in the construction of the software system can reduce expenses, minimize the cost of data storage, etc. The modern development of the world economy is accompanied by the wide application of information systems, among which cloud technologies have a special place. For this, cloud computing, their features and services are investigated, related works and the most common cloud computing models and cloud databases are studied. Digital twin technologies, their types, etc. are studied to increase the software system performance in cloud computing, forecasting, monitoring, and to reduce production time. Reliability criteria for software systems in cloud computing are selected. The calculations based on the obtained scientific results perform promising results.

Keywords: Cloud computing, cloud technology, digital twins, reliability, criteria, twin technologies

Introduction

Nowadays, various technologies are used in software systems' construction. These technologies play an important role in increasing the system efficiency. One of these technologies is cloud computing.

In general, cloud computing enables users to store and manage data efficiently. It also has the extra benefits of data security, encryption, regular backups, and cloud software hosting. Many cloud computing models are available. The three most common cloud computing models are as follows:

- **Public cloud:** Controlled by the service provider;
- **Private cloud:** Managed by the organization's own department or individuals;
- **Hybrid cloud:** Combination of the first two (Public and private) models.

Hybrid cloud enables enterprises to manage certain services themselves and use the cloud for some client applications [8]. Currently, new useful functions are added to cloud computing models, which greatly increase their efficiency.

This work aims to develop a method for creating distributed software systems on cloud system platform and improving their reliability.

This process includes several stages.

Cloud computing provides the development and use of computer technology infrastructure and software directly in a network environment. With their help, the user data is stored in cloud systems, processed and the results are viewed [1, 21].

Three main cloud computing services are available [11]:

- Infrastructure-as-a-Service (IaaS);
- Platform-as-a-Service (PaaS);
- Software-as-a-Service (SaaS).

IaaS includes the basic elements for a cloud system.

PaaS does not require an organization's control database infrastructure and maintains the use and control of any application.

SaaS - a user purchases a ready-made software system managed by the provider of this service. In this case, applications are often used for end users. The analytical center of the International Data Corporation (IDC) performs analysis and forecasts on information technologies (IT). The forecast for 2016 estimate the expenses spent on the creation of cloud computing to increase from 101 billion to 250 billion USD in 2023 [2].

This IDC study forecasts the revenue for 20 key categories of public IT cloud services across 8 geographic regions worldwide. IDC's 2019-2023 forecast for global and regional public IT cloud service spendings represents the cloud's rapid emergence as the foundation for digital innovation in every industry and the preferred service and data consumption model for consumers. In particular, the public cloud model has become a training ground for digital technology innovations for security, digital infrastructure, data, Internet of Things (IoT) services, etc. IDC Senior Vice President and Chief Analyst Frank Gens (Chief Analyst Emeritus at IDC) believes that "the next five years will be an important period for public cloud service providers and their customers. Enterprises that use digital technology streams weekly deployed in public clouds quickly and perceptively are the most likely to be leaders in the digital economy. We will see the power of public cloud providers grow significantly as they deliver distributed cloud offerings outside their own data centers more quickly, i.e., in enterprise data centers, distributed facilities such as retail stores and factories, and mobile phones" [2].

The use of cloud computing in the construction of the software system leads to a reduction in expenses and the minimization of data storage costs.

When a certain algorithm is applied to a large data set, a machine learning model is used for this, and the cloud is important for it. Prospective learning models learn from a set of samples from available data. The more information is provided into this model, the better the predictions and the higher the accuracy will be achieved. For example, thousands of X-ray reports are used to train a system for a machine learning model to identify tumors in medicine. Moreover, this template is then customized according to the needs of the project, so it can be used in any field. Thus, data comes in many forms, including on-demand, raw data, and unstructured data [12].

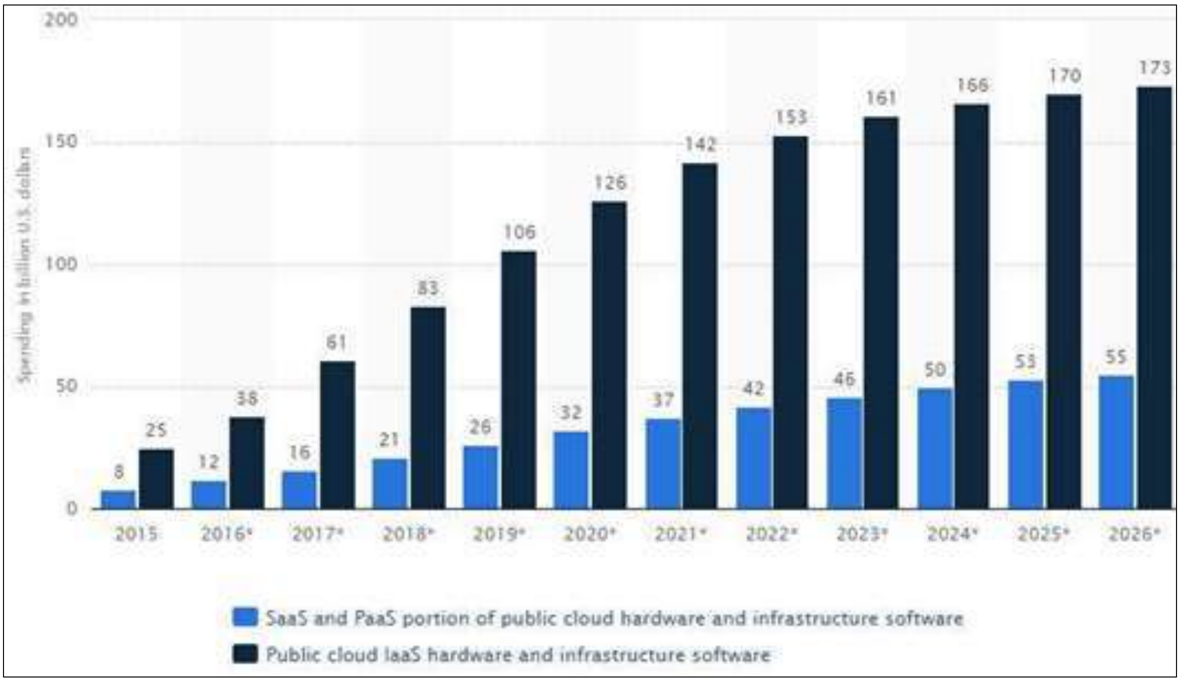

Fig 1: Public cloud Infrastructure as a Service (IaaS) hardware and software spending from 2015 to 2026, by segment (in billion U.S. dollars)

Related works

The current development of the world economy is accompanied by the wide application of information systems, among which cloud technology begin to occupy a special place. It gradually becomes one of the most important factors influencing the increase of competitiveness of companies in various industries and fields of activity.

Cloud computing is an evolving technology and its use in various fields has its advantages. As mentioned, in cloud computing, a user can access their files or data from anywhere via the Internet. Cloud computing has advantages such as cost reduction, security, etc. [13].

The lack of effective approaches to increase the efficiency of the use of cloud technologies predetermines the expediency and importance of a comprehensive assessment of the advantages and limitations of their use, as well as further development prospects.

Advantages of cloud computing.

1. One more advantage of cloud services manifested in reliability is that the basis of their software and hardware is security, professional staff, reserved power supply, permanent data backup, etc. [13].
2. Superior performance. In cloud computing, more work is done in less time with fewer workers;
3. Cost reduction. In cloud computing, the user divides the computer hardware, software and data into several parts, so there is no need to spend more money on hardware or software;
4. Ease of access. The user can access data and files in cloud computing via the Internet at any time from any place;

5. Less training required. Fewer workers are required for the work done in cloud computing [3].

Disadvantages of cloud computing

Along with advantages, the use of cloud technologies is accompanied by a number of problems [13]:

1. Access to cloud services requires a permanent connection to the Internet provided;
2. The privacy of data stored in public clouds causes a lot of controversy. In this regard, many experts do not recommend storing the most valuable company documents in public cloud, because today there are no technologies to ensure the complete security of the stored data;
3. In case of violations in the data backup system, the company faces the risk of completely losing the data stored in "cloud";
4. Despite the reliability of cloud data storage, there is always a possibility of "hacks" by various intruders; in this case they will be able to obtain a large amount of information with all subsequent consequences.
5. Companies must allocate significant financial resources to create their own "cloud", which can only be justified if these technologies are used on a large scale.

The National Institute of Standards and Technology (NIST) describes cloud computing with five key characteristics:

- On-demand self-service;
- Provision of wide network access;
- Ensuring flexibility;
- Pooling of resources, etc. [4].

The rise of mobile cloud computing (MCC) and the presence of dynamic changes in network bandwidth are driving the need for mobile clients to be resource-accessible and adaptive to the environment. These can be processed through Big Data and Cloud Computing is used in this case [5].

In MCC widely uses mobile devices and applications. Many problems arise when using mobile devices in MCC. In MCC, mobile services are presented as a potential technology for processing information from mobile devices in the cloud, storing data there and solving the problems of mobile resources [6].

Some research presents a SmartRank approach to offloading for mobile applications using cloud computing. This approach is used for symbol recognition based on resource evaluation with the help of cloud computing indicators. In addition, it is evaluated in several ways. One of them is implemented with the help of modeling the system (continuous-time Markov chain) [7].

Cloud computing and its features

Below are the features of cloud computing

1. Hyperscale and virtualization: Cloud computing provides the most reliable and secure data storage center. Users will not have to worry about data loss, virus intrusion and other issues. At the other end of the "cloud" are the world's most professional teams supporting information management and the most advanced data centers helping to store data [8].
2. Customer demand: Cloud computing requires the minimum amount of equipment from the customer side and is very convenient to use. For example, antivirus and firewall software should be installed to prevent viruses during downloading. With cloud technology, cloud computing can be used successfully as long as every computer and browser has access to the Internet.
3. Easy data sharing; Cloud computing can perform data and program sharing between different devices. In the network application model of cloud computing, all electronic devices can access the same data at the same time simply by connecting to the Internet.
4. Robust scalability: Cloud computing is not a dedicated application. By supporting the "cloud", various applications can be built according to the needs of users. The scale of the "cloud" can also be dynamic.
5. Traditional Data Processing System and intelligent Cloud Computing Data Processing System. At present, various colleges and universities have two problems: lack of scientificity and precision in recruiting graduates;

Low level of use of entrepreneurial information;

Obtaining accurate business information and using it efficiently;

Processes and standards without a set of scientific entrepreneurial data. Table 1 illustrates current problems in entrepreneurship data collection.

Table 1: Problems existing in entrepreneurship data collection.

Years	Utilization level	Use awareness	How to use
2015	36%	52%	Single
2016	31%	49%	Single
2017	28%	38%	Single
2018	40%	42%	Single
2019	37%	45%	Single

Cloud computing typically has the following functional features

1. On-demand self-service that enables a consumer to identify and measure their computing needs without contacting a service provider representative;
2. Universal access over the network, which allows receiving services over the data network regardless of the terminal device used;
3. Pooling of resources, which allows the service provider to unify resources in one place to serve a larger number of consumers, for dynamic reallocation of capacity among consumers in ever-changing capacity demand;
4. Flexibility, which provides services at any time, expanding and narrowing their range, without additional costs for interaction with suppliers;
5. Accounting of consumption, which allows the unification of consumed resources using a certain level of abstraction, for example, the amount of stored data, bandwidth, number of users and operations, etc. [9].

The International Data Corporation (IDC) supports decision-makers in situations of alternative choices, when their knowledge, experience and intuition are not enough to solve the problems arisen on their own, thus, the manager must be aware of up-to-date information about mobile access that can be provided through the latest Internet technologies, i.e., clouds. Establishing such systems will reduce business management costs and minimize the cost of data storage unit. The concept of cloud computing provides new opportunities for the development of decision support systems in small and medium-sized businesses.

Currently, cloud computing models are provided with a growing number of new functions [10]. Describes a laboratory model of an intelligent system, which allows testing the practical use of cloud computing in programming components for the system. Cloud computing elements are used in this regard. The innovative features of the services transferred to cloud computing models consist of the integration of systems based on Information Technology (IT) and Internet technologies with joint intelligent management of users' services.

About cloud databases

A cloud database is a database created in a cloud environment, such as a private, public, or hybrid cloud. There are two main models for deploying cloud databases.

1. Traditional database;
2. Database as a Service (DBaaS).

The first model is very similar to a database hosted locally and managed internally. The difference is in the way infrastructure is provided. The company buys a virtual domain from a cloud service provider and the database is hosted in the cloud. Enterprise developers use a development & operations (DevOps) model or involve IT staff in database management. The user is responsible for controlling and managing the database.

DevOps is a technique for automating the technological processes of assembling, configuring and extending software.

The term brings together the cutting edge of software development and technology operations, as DevOps integrates development and operations activities.

The second model enables the company to sign a contract with a cloud service provider and provide a paid subscription to its services. The service provider offers a range of capabilities to ensure the end user with real-time tools for handling various tasks related to operations and database control, as well as maintenance and administration. This database runs on the service provider's infrastructure. This model typically offers automation for resource management, backup, scaling, automatic high availability, and system health monitoring. The Database-as-a-service (DbaaS) model is most beneficial to companies, since it allows them to use database management tools as software automation tools instead of hiring and managing database professionals.

Cloud databases have several advantages offered by different cloud services. Figure 2 presents some of them.

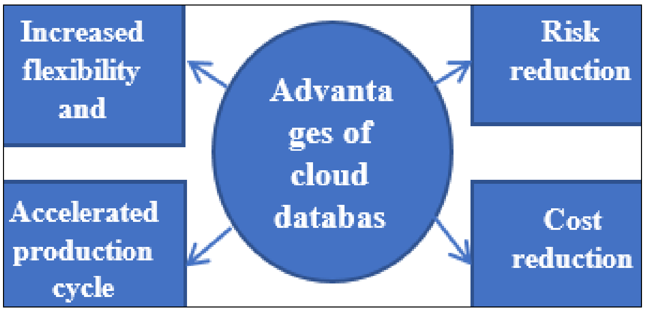

Fig 2: Advantages of cloud database

Cloud database managed by customer

In this model, the company's employees deploy the database in the cloud infrastructure, but manage it by their own experts and automation tools (no automation tools are required from the cloud provider). This model offers the standard benefits of a cloud environment (such as increased flexibility, customization level, etc.), but the customer is responsible for managing the database.

There are many types of cloud databases, each designed to achieve a specific goal and handle specific workloads. For example, some databases are specifically designed to manage transactions, others to run web applications, to serve as data warehouses or data marts for analytics.

Cloud databases can benefit almost every industry, from the financial industry to the healthcare industry. The question is not whether to use a cloud database or not. The question is to decide which model and which database is best for a given task in businesses.

Many companies are performing a new approach to using cloud databases by combining traditional cloud database models with DBaaS models. Others (such as those in the financial services industry) prefer to leave critical applications in place.

However, the situation is changing rapidly. DBaaS models are becoming more robust and more companies are shifting to separate cloud databases, so businesses are likely to discover great opportunities and gain significant benefits if they move their entire databases to cloud.

Self-managed databases are designed to avoid facility failures, even when hosted on cloud platform facilities. Such databases offer installing all the necessary software, virtualization and clustering tools online. They ensure easy scaling performance and adjustment of the efficiency level according to current needs. Furthermore, they protect data from both external and internal attackers and prevent many problems.

About Digital Twin technology

A digital twin (DT) is a virtual model of a physical object. It covers the lifecycle of an object and uses real-time data sent from the object's sensors to model behavior and control operations. DTs can reproduce a variety of real-world objects, from individual pieces of equipment in a factory to wind turbines and even entire cities. DT technology monitors the operation of the object, identifies possible failures and makes more informed decisions about maintenance and life cycle [14].

DT offers many advantages to users. Some of them are presented below.

Performance improvement: The real-time data and analytics provided by DT optimize the work of equipment, plants, facilities, etc. Problems can be fixed as they arise, keeping systems running at peak performance and reducing downtime.

Forecasting skills: DT can offer a complete visual and digital representation of a manufacturing plant, commercial building or facility, even if it consists of thousands of pieces of equipment. Smart sensors monitor the output of each component, recording problems or malfunctions. Instead of waiting for equipment to fail completely, measures can be taken at the first sign of problems.

Remote monitoring: The virtual nature of DT is that it can control and manipulate objects remotely. Remote monitoring also requires fewer people to inspect potentially dangerous industrial equipment.

Reduction of production time: By creating digital copies, manufacture of products and objects can be accelerated even before they are available. By running the scripts, it can be seen how the product or object reacts to failures and the necessary changes can be made prior to the production.
A number of fields are increasingly using DT to create virtual representations of their real systems. Below are some examples.

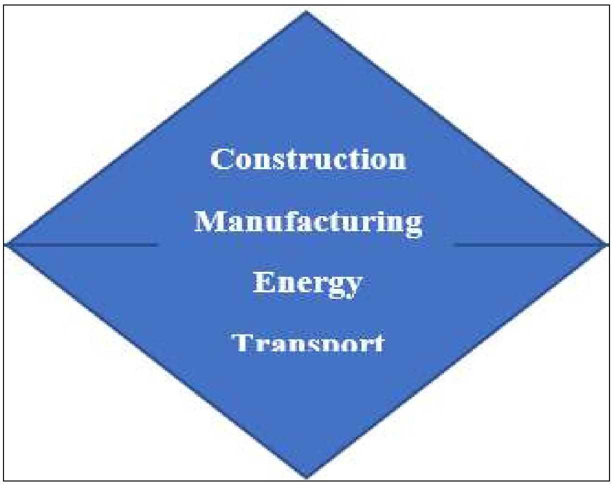

Fig 3: Some areas using digital twins

The most common types of DTs are as follows:
1. Component Twins;
2. Object Twins;
3. System Twins;
4. Process Twins, etc.

Digital Twins Cloud Platform Concept
It provides an Application Programming Interface (API) and develops a cloud platform that ensures the dynamic allocation of computing resources to ensure the DT execution and to present the DT as micro services. Thus, Digital Twin as a Service (DTaaS) presents the cloud model. The DTaaS model represents DT as a set of cloud services for storing and analyzing sensed data, modeling real objects and visualizing them in a virtual presentation [15].

DTs cloud platform provides the following levels
- **DT user level:** At this level, the user can access existing DTs in the form of cloud applications using the software model.
- **DT developer level:** At this level, the cloud platform provides resources for DT development based on the platform-as-a-service model. DT is described as a computing workflow whose nodes correspond to computing services and other DTs, and whose relationships correspond to the data flow between nodes.
- **Computing service developer level:** At this level, the cloud platform provides an Application Programming Interface (API) for the development of back-end computing services as a service model. A computing service is represented as a micro service that is responsible for certain data processing operation or execution of certain computing methods.
- **Cloud infrastructure provider level:** At this level, computing service instances are adapted to cloud computing resources provided by the cloud platform based on the container service model.

The following main actors interacting with the DT cloud platform can be distinguished (Figure 4).

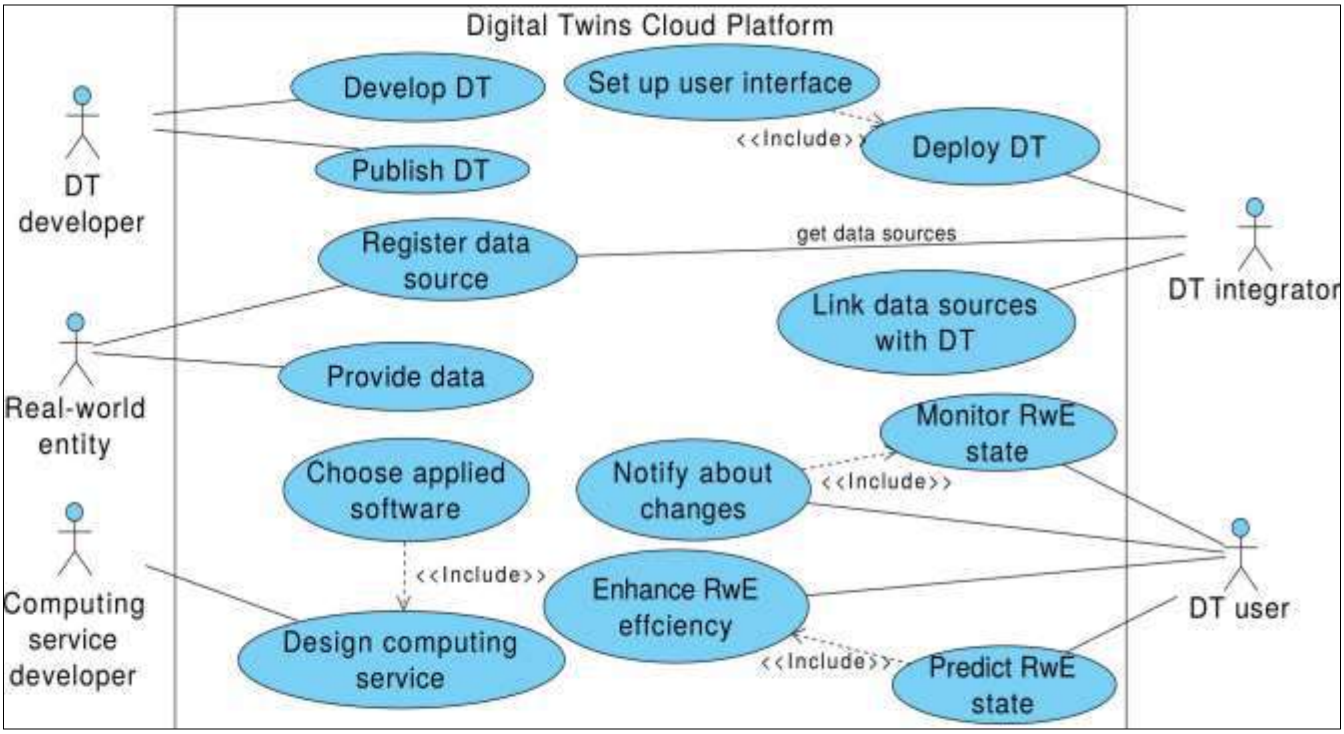

Fig 4: Digital Twins Cloud Platform use-cases

DT user uses DTs to get the necessary information about real-world entities, such as their status, notification of real-world entity state changes, prediction of their behavior and parameters under certain conditions, real-world entity recommendations, real-world entity efficiency, etc.

1. DT integrator is responsible for the connection of real-world objects with virtual representatives, the construction and provision of DT user interfaces, the deployment of DTs in objects.
2. DT developer uses the DT Cloud Platform Computing Services to develop it.
3. Computational service development designs computational services that implement models of real-world objects using components developed in conjunction with existing application software packages.
4. Real-world entity is a real-world process, system, or device equipped with sensors. These sensors collect data and send it to DT cloud platform for storage and analysis. Correspondingly, the data can be obtained from data sources such as SCADA, MES, etc. and collected manually.

As further research, it is planned to design the architecture of the cloud platform that supports the DT implementation and to present the resource management methods of the cloud system through the Container-as-a-Service (CaaS) model.

8. Development of a method for criteria selection for software systems in cloud computing and improvement of reliability

Reliability of software systems in cloud computing is the ability to perform tasks under the required conditions within a specified time. The main reliability criteria are [18]:

- Operational capacity;
- Non-failure operation;
- Sustainability;
- Maintainability;
- Retention.

Operational capability is the state of the device that can perform the specified functions while maintaining the parameter values specified in the specified scientific and technical documents.

The probability of non-failure operation P (t) refers to the probability that the software system will not fail in a certain time interval. The probability of non-failure operation is determined by the following formula [16]:

$$P(t) = \frac{N-n}{N},$$

$$N = 100, n = 20,$$

P (t) = (100-20)/100=0,8

Where

N is the initial number of the software product; n - the number of software products failed during time t. The probability of non-failure of complex software products is equal to the product of the probabilities of failure of its individual elements: $P(t) = P_1(t) * P_2(t) \ldots P_n(t)$

Failure intensity $\lambda(t)$ is the ratio of the number of failed software products n per time unit t to the number of currently working products $N - n$:

$$\lambda(t) = \frac{n}{(N-n) * t}$$

$$\lambda(t) = 20/(100\text{-}20)*1=0,25,$$

The probability of non-failure operation can be estimated by the failure probability:

$$P(t) = 1 - \lambda(t) * t$$

$$P(t) = 1 - 0{,}5 * 1 = 0{,}75$$

According to operating standards, sustainability is the ability of software systems to maintain their performance for a long period of time until a critical condition occurs. A critical situation refers to a situation in which further operation of the software product is unacceptable or impossible. Sustainability is characterized by technical and gamma-percentage resources.

Technical resource - the total operating time of software product from the start of operation of the product to the transition to the limit. The allocated resource is the total runtime of the software product, regardless of state.

Maintainability is the ability to prevent, detect, and correct software product failures.

A failure is a violation of the functionality of software product. Progressive failures are characterized by the gradual progress of this or that damage process gradually deteriorating the output parameters of the object.

Abrupt failures occur as a result of a combination of adverse factors and random externalities exceeding the software product's ability to perceive them. Abrupt failures are characterized by the abrupt nature of the transition of the product from a working state to a non-working state.

Compound failure includes the features of the two previous failures [16].

Reliability indicators should be understood as quantitative characteristics of one or more reliability criteria, indicators related to one of the criteria are simple, and those related to several ones are complex. The measures are different for recoverable and non-recoverable software products.

Cloud systems refer to recoverable systems. The main reliability indicator for cloud storage and data processing systems is: availability of services and reliability of operation.

The main risks of cloud computing are related to operational reliability and service availability.

Errors may occur after the removal of programs or due to defects in some devices, which can affect the operation of the system and consequently cause critical failures in the operation of the entire system.

Even if the server is unavailable for a few seconds, all the received requests will be lost and many users will not be able to get responses to their requests.

Resending of requests or packets can be used to overcome such errors, but this approach can cause large delays in processing requests and increase the load on servers, as

users will send repeated requests without waiting for a response to the request.
Service availability can be calculated by formula (1) [16].

$$D = \frac{T_0}{T_0 + T_n} \qquad (1)$$

Where
T_0 is the time between failures, T_n is the system downtime.
$T_0 = 2, \quad T_n = 10$

The values of T_0 and T_n can be calculated both theoretically and practically based on previous information about the operation of the system as a whole. However, it is not possible to save all system monitoring data anyway. Formula (2) can be used to calculate the system availability based on the downtime T_n and the scheduled system operation time T_{zn}.

$$D = \frac{T_{zn} - T_n}{T_{zn}} \qquad (2)$$

D=(15-10)/15=0,33

The reliability of operation can be found by formula (3).

$$H_e = \frac{\mu y}{\mu o} * 100\% \qquad (3)$$

Where
μy is the number of successful requests and μo is the total number of requests.

H_e=40/50*100%=0,8

Since the reliability is currently very high, it is more convenient to calculate the reliability by formula (4), which calculates the number of failed requests per 100 requests.

$$DPM = \frac{\mu o - \mu y}{\mu o} *1000000 = \frac{\mu hy}{\mu o} *1000000 \qquad (4)$$

DPM=(50-40)/50*100=20

Formula (5) converts the number of failed attempts per million into service reliability value, whereas formula (6) converts service reliability value into the operational reliability.

$$H = \frac{1000000 - DPM}{1000000} *100\% \qquad (5)$$

H=(100-20)/100*100%=0,8

$$DPM = (100\%-H)*1000000 \qquad (6)$$

DPM=(100% - 0,8)*100=20

The real-time or request execution speed by the cloud service is evaluated by the temporal indicator Ti.

These include performance metrics, bandwidth, average request processing time, average request waiting time before processing.
Due to the data redistribution of tasks to be solved between cloud servers, including the reduction of Ti indicators, the performance of the entire computational model is maintained.
The following methods are used to increase the reliability of the stored data [17]:

- Backup files;
- Archiving backup files;
- Restricting the data access;
- Applying restrictions;
- Applying residue class system.

When backing up files, their copies are created on the machine's storage medium and systematically updated when there are changes to the backup files. This method makes a simple copy of one or more files or file structures [18].
The main disadvantage of this method is that it requires the same amount of disk space as the source files to store the backups. When storing large amounts of data, it will significantly increase equipment maintenance and storage costs.
The archiving method uses the same storage scheme, except that the backup is compressed before being written to the storage media to reduce the amount of disk space stored.
Compression degree depends, firstly, on the type of file, and secondly, on the archiving program. Database files and text files are the most compressed, while binary files (such as EXE and COM) and images are the least compressed. An archive file contains a table of contents that informs what files are archived. This method reduces the costs compared to the method discussed above, however, it is not very suitable for cloud structures.
The computational model for data processing in cloud systems consists of k working and r control servers. If working servers fail, they can be replaced by control servers and vice versa.
Providing guaranteed protection from ensuring the required output to the computing scheme requires at least one control server to be kept in operational state.

Conclusion

This study mainly concludes that cloud computing is a tool for innovation in other emerging technologies (data modeling, the Internet of Things, virtual reality, augmented reality, Big Data analytics) in various fields [19].
Cloud computing platforms have become part of the basic global infrastructure. As a result, the non-functional characteristics of cloud computing platforms, including availability, reliability, performance, efficiency, security and sustainability, are extremely important. However, the distributed nature, pure scale, and complexity of cloud computing platforms, i.e., from storage to networking, computing and more, create great problems for the construction and operation of these systems [20].
The computing model of data processing in cloud systems consists of working and control servers. If working servers fail, they can be replaced by control servers and vice versa.
Providing guaranteed protection from ensuring the required output to the computing scheme requires at least one control server to be kept in operational state.

In further research, new methods and technologies are required to increase the reliability of distributed software systems on cloud platforms, which will reduce costs and eliminate deficiencies, etc.

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