The Method of Calculation the Total Migration Time of Virtual Machines in Cloud Data Centers

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***Abstract*—Cloud applications and services such as social networks, file sharing services, and file storage have become increasingly popular among users in recent years. This leads to the enlargement of data centers, an increase in the number of servers and virtual machines. In such systems, live migration is used to move virtual machines from one server to another, which affects the quality of service. Therefore, the problem of finding the duration of migration is relevant. This paper proposes a method for finding the probability density of the total migration time based on the derivation of an analytical expression and using the Gram-Charlier and Laguerre series. It is shown that the Laguerre series gives the best approximation.**

I. Introduction

Cloud applications and services such as social networks, file sharing services, and file storage have become increasingly popular among users in recent years. For example, YouTube users download about 300 hours of video every minute and watch hundreds of millions of hours every day [1]. The growth of data volumes according to Cisco forecasts will double by 2021 compared with 2017, which requires the construction of new data centers [2]. Moreover, there is a tendency to concentrate processing and storing data in largescale data centers with thousands of servers and tens of thousands of virtual machines.

Virtual machine migration is a transfer of a running virtual machine from one physical server to another. Migration is used in data centers to consolidate virtual machines on fewer physical servers, load balancing and reduce server overheating [3].

Despite the fact that the migration can be carried out without stopping the service, the deterioration of the performance of virtual machines and short-term downtime is still inevitable. In [4], it was shown that the downtime can vary significantly from 60 ms to 3 seconds depending on how the application uses memory. Moreover, the migration additionally loads servers and the network, which leads to the decrease in application performance and affects the server monitoring process [5]. Therefore, the development of a method for calculating the duration of migration is an urgent task necessary to maintain the stability of migration and ensure the quality of service.

This paper is organized as follows. Section II provides an overview of migration types and their features. Section III provides an overview of related works. Section IV presents the algorithm for calculating the probability density of the total migration time. Section V gives an approximation of the probability density of the duration of migrations by the Gram-Charlier and Laguerre series. Also in this section, an algorithm is given for estimating the total migration time. The main results of the work are given at the conclusion.

II. Types of virtual machine migration and their features

A. Types of VM Migration

- Stop and Copy [6]. With this type of migration, the virtual machine is suspended on the source host, all memory pages are copied to the target host, after which the new virtual machine is launched. This method is quite simple. The total migration time is relatively small compared to other techniques and is directly proportional to the active memory size of the migrating VM. However, a virtual machine can have significant VM downtime depending on the amount of memory, and as a result, this approach is impractical for many services.
- Pre-copy migration [4]. This approach is used in most hypervisors, such as Xen, VMware and KVM. The hypervisor initially copies all memory pages of the original VM to the new VM, while the operating system remains working. After that, there are a number of iterations for which the modified pages are copied. Finally, the original VM stops and all the remaining pages are sent to their destination VM. All services on the destination host are then resumed. This approach takes precedence over full stop-and-copy because of the decrease in VM downtime, since the virtual machine continues to work as long as possible during migration. But since the migration process is associated with the copying of ”dirty” memory pages, the total migration time is usually longer.
- Post-copy migration [7]. This migration type assumes that memory and processor states are transferred to the destination VM immediately. The rest of the resources will be copied either in the background or on demand. For example, if a process on a new VM requests a page that has not yet been copied, this causes the hypervisor on this node to copy the missing pages from the source node. This approach allows to minimize VM downtime, but significantly increases the total migration time. In addition, the user may experience longer response time when the memory pages are copied on demand.

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- Hybrid Migration. Since different types of migration have advantages and disadvantages, a lot of works have appeared recently, in which various hybrid types of migration have been investigated [8], [9].

B. Stages of pre-copy migration

The most common type of migration implemented in most hypervisors, such as Xen, VMware and KVM, is the pre-copy approach. The duration of such a migration consists of several stages [4].

- Stage 0: pre-migration. Host A hosts an active virtual machine. The target host B is selected for migration. Block devices on host B are mirrored and free resources are reserved.
- Stage 1: reservation. Initializing the container on the target host.
- Stage 2: iterative pre-copy. For the first iteration, all memory pages are copied from host A to host B. In subsequent iterations, only copies of those pages that were modified during the previous transmission phase are transmitted. The number of iterations is limited in the hypervisor settings. For example, in Xen hypervisor, the maximum number of iterations is 29 times.
- Stage 3: stop-and-copy. On host A, the running instance of the OS is suspended, and all network traffic is switched to node B. Registers and cache memory of the processor are transferred, as well as all remaining unmatched pages of memory. At the end of this stage, hosts A and B have permanent suspended copies of virtual machines. Copy A is still considered the primary and resumes in the event of a failure.
- Stage 4: Commitment. Host B notifies Host A that it has successfully received a consistent OS image. Host A can now abandon the original virtual machine, and Node B becomes the primary host.
- Stage 5: activation. The migrated virtual machine is activated. Local devices are connected and network environment is set up.

C. The characteristics of virtual machine migration

The performance of live migration is estimated by several indicators [7]. The most important of them are:

- Total migration time. This is the total time of all stages of the migration from the beginning to the end. The total time is important because it affects the release of resources on both participating nodes, as well as within the VM itself at both nodes. Furthermore, it interferes into server monitoring process of the resource management system and affects the quality of service. The common approach to minimize total migration time is compression of memory pages [10], [11].
- Downtime. It is the time during which the migrating virtual machine stops. At a minimum, this time includes transferring the processor state. For a pre-copy, this transfer also includes all the remaining dirty memory pages. For post-copying, this involves the transfer of some other parameters, if any, needed by the VM to start on the destination host.
- Application performance degradation. This is the extent to which migration slows down the application running in the VM. Pre-copy must track dirtied pages by trapping write accesses to each page, which significantly slows down write-intensive workloads.

In terms of quality of resource management, two more indicators are important:

- Total number of migrations. It was noticed that poor-quality forecasting of host overload increases the number of unnecessary migrations and their total number. In addition, the number of migrations is strongly affected by the threshold value of the host overload, the larger it is, the fewer migrations it causes, but the more risk to violate SLAs [12].
- The number of reverse migrations (ping-pong migration). Migration can be considered unsuccessful, if soon after moving the VM to the server it must be returned back. This indicator adds to the total number of migrations. In addition, if there are many such returns, the system itself will be unstable, as its resources will be wasted for unnecessary migrations, the number of which will increase. In order to avoid this, it is necessary to predict the state of the server after the virtual machine is migrated on it [5].

III. Related work

A number of works are devoted to the study of migration processes. In particular, in [13] was proposed the method of minimizing the virtual machine downtime during migration by finding the optimal number of iterations to copy memory pages. The method is based on the implementation of two algorithms: predicting the number of iterations of copying "dirty" memory pages and reducing the size of the required RAM when migrating.

In [14], [15] analytical models were proposed for estimating the average migration time of virtual machines and the service downtime during the transfer, depending on the amount of RAM, the speed of modification of memory pages and network bandwidth.

In [16], the authors used machine learning methods to model live migration and predict its characteristics. The full information about the random value gives knowledge of its distribution law. In [18] an analytical expression for the probability density of total migration time is obtained. However, at present there is no clear sequence of calculations in order to obtain the probability of the duration of migration.

IV. Numerical characteristics of random variables describing the migration process

In the works [14], [18] the total time of pre-copy migration is given, which is the sum of times of the migration stages.

In this formula there are deterministic and random components of migration process. Deterministic components include all operations except iterative copying and their duration depends on the computer system and the hypervisor. The duration of the random components depend on the network bandwidth, the amount of RAM and the speed of modification of memory pages. In [18], the minimum deterministic time of migration process was determined, which is called the elementary operation of the migration process.

The number of migrations was found by simulation modeling using the CloudSim library, in which most samples corresponded to the Poisson distribution. To determine the number of elementary operations, the migration database [16] was used, containing five types of migrations (pre-copy, post-copy and with the compression of memory pages), approximately 8000 records of each type.

The expression relating the duration of the migration τ_i to the relative number of elementary operations for the migration time *X* and the number of migrations *N* for the observation period *T* can be written as follows:

$$X = k_0 \sum_{i=1}^{N} \frac{\tau_i}{t_{min}}. \quad (1)$$

where t_{min} is the minimum duration of an elementary operation;

$$k_0 = \frac{t_{min}}{k \cdot T_0}. \quad (2)$$

where T_0 is the length of the monitoring window;

k is the number monitoring windows.

By statistics processing, it is concluded that the number of elementary operations for the period *T* is close to the normal distribution.

The least squares method selected their dependencies of the parameters of the number of elementary operations $\alpha(T)$, $\sigma(T)$ and the number of migrations $\lambda(T)$ on time, which are nonlinear. It is also shown that their ratio has a finite limit [18].

Using the theory of characteristic functions on the basis of the known distributions of the relative number of elementary operations X and the number of migrations N, an approximate expression was obtained for the probability density distribution of the duration of migration, shown in Fig. 1.

The calculation algorithm is as follows:

1) Collect data on the number of *N* migrations and the number of elementary operations in the *X* migration for the observation periods *T*.
2) Estimate the parameters of the distribution of the number of migrations and the number of elementary operations.
   $\lambda(T)$ — the intensity of the appearance of the number of migrations distributed according to the Poisson law;
   $\alpha(T)$ — expectation of the relative number of elementary operations, normally distributed;
   $\sigma(T)$ — is the variance of the relative number of elementary operations.

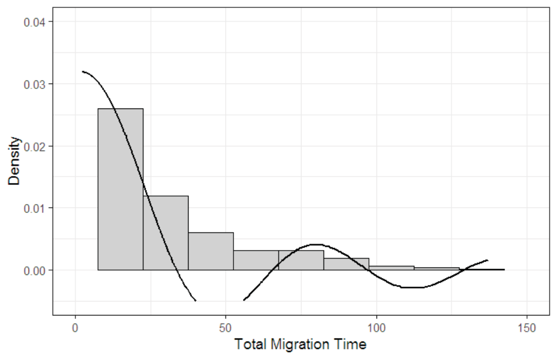

Fig. 1. Approximation of the duration of migration by the expression of the probability distribution density

3) Using the least squares method, find the time dependencies of the parameters $\alpha(T)$, $\sigma(T)$ and $\lambda(T)$. and the values of the coefficients γ and β in the models given in [18].
   With post-copy migration type take $\lg X$.
4) Find the limits of the ratios of the coefficients c_1 and c_2, see [18].
5) Substitute the obtained coefficients in the expression for the density distribution of the duration of migration [18].

V. Approximation of the Distribution Density of the Total Migration Time

To simplify the calculations, it is proposed to approximate the probability distribution density by series, for which the Edgeworth series was chosen, which is based on Chebyshev-Hermite polynomials [19]. For practical calculations, a finite number of elements of the series is called the Gram-Charlier series. Also, the Laguerre series was selected. The results of data processing are presented in Fig. 2 and Fig. 3.

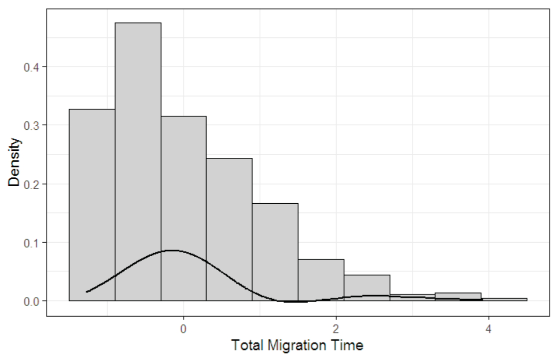

Fig. 2. Approximation of the probability distribution density of the total migration time with the Gram-Charlier series

The experiments have shown that the Gram-Charlier series give an acceptable approximation for sampling data with a small skewness. In Fig. 2, the empirical distribution function has a large coefficient of skewness. The algorithm to build a Gram-Charlier series is as follows:

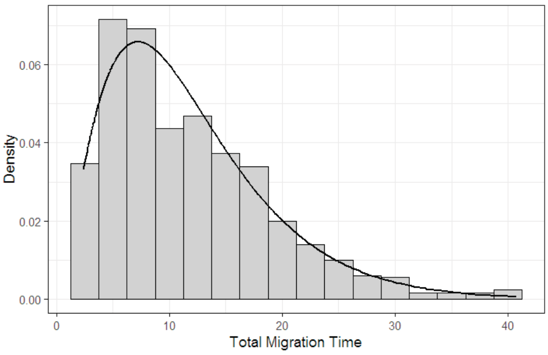

Fig. 3. Approximation of the probability distribution density of the total migration time with the Laguerre series

1) Find the estimate of the mathematical expectation and the variance for total migration time.
2) Normalize the variable.
3) Calculate the coefficients of skewness and kurtosis.
4) Build a series according to [19]. Derivatives of the Laplace function are tabooed.

The algorithm for constructing the Laguerre series is as follows:

1) Find the estimate of the expectation and the variance for a random variable.
2) Calculate alpha and beta.
3) Build a series according to [19].

VI. Conclusion

As a result, it was concluded that the approximation with the Laguerre series gives the best result.

The proposed method for calculating the duration of migration will allow us to obtain in practical calculations the probability of a given duration of migration, as well as to estimate the accuracy of its calculation.

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