IMPROVING THE EFFICIENCY OF USING THE RESOURCES OF VIRTUAL DATA CENTERS WITH A HETEROGENEOUS STRUCTURE BY REPOSITIONING VIRTUAL MACHINES

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Abstract: The article presents an approach to managing virtualized data centers (VSDDC), which are based on virtual machine hypervisors – software management modules that allow multiple virtual machines to use the resources of a single server platform. The aim of the work is to increase the efficiency of using VSDDC resources with a heterogeneous structure through the development of mathematical and software for the relocation of virtual machines. As a result, a model of multidimensional representation of virtualized resources has been developed, taking into account the normalized value of their use by live migration algorithms and providing the possibility of calculating their imbalance, which determines the need to perform the process of repositioning virtual machines; an algorithm for repositioning virtual machines has been created based on a reasonably chosen method of solving the problem of multidimensional combinatorial optimization; an architecture of a software-implemented support system for repositioning virtual machines in VSDDC has been proposed with a heterogeneous structure; An experimental study was conducted to evaluate the efficiency of using VSDDC resources based on the proposed algorithm for solving the problem of reallocation of virtual machines for various variants of the VSDDC structure.

Key words: virtualized data centres, virtual machine hypervisors, heterogeneous structure, relocation, migration algorithms.

1. INTRODUCTION

The technological implementation of remote execution of tasks on demand has become possible due to the development of data processing center (DC) architectures, which provide data mining technologies with the necessary computing and communication resources, such as processor time, RAM, data storage and bandwidth of communication channels. The peculiarities of each of these resources do not allow to unify their use by one parameter, and require a comprehensive multidimensional approach to their consideration.

In the SDDC domain (SDDC – software defined datacenter), an important research issue is to increase the efficiency of providing its resources to users, which can be solved by scaling the hardware infrastructure or implementing resource virtualization tools. Virtualized or software-defined SDDC are based on virtual machine hypervisors – software management modules that allow multiple virtual machines to use the resources of a single server platform (hereinafter referred to as a physical machine).

The aim of the work is to increase the efficiency of using virtualized SDDC (VSDDC) resources with a heterogeneous structure through the development of mathematical and software for the relocation of virtual machines.

2. THE STATE OF THE PROBLEM

In the process of servicing multiple user requests [1] in VSDDC, dynamic redistribution of physical machine resources between multiple virtual machines is required to balance the load and increase the efficiency of using virtualized resources [2]. This is necessary to eliminate "hot spots" and to optimize overall energy consumption, including putting a subset of machines into inactive mode and freeing up resources for additional tasks. This process is known as VM consolidation [3], and its effectiveness is measured by the utilization factor of physical machines: the ratio of the number of inactive VSDDC physical machines to their total number $K_F^U = \frac{N_F^{InA}}{N_F^{Full}}$. It is calculated at the end of the polling cycle of physical machines and the calculation of the normalized value of the utilization of virtualized resources on each of them by the VSDDC administration service monitoring system.

The basic way to solve consolidation is the dynamic process of reallocation (re-placement) of virtual machines between physical machines [5] through VM migration: live or delayed. The increase in the scale of VSDDC, due to the increased demand for virtualized resources, makes the issues of effective use of these resources very relevant, which, in turn, requires improvement of models, methods and algorithms to solve the problem of reallocation of virtual machines.

At the same time, most of the mechanisms for repositioning virtual machines implemented in modern hypervisors are based on iterative procedures that use variants of greedy algorithms that operate under a number of restrictions and do not fully take into account both the multidimensionality of virtualized resources and the specifics of implementing specific live migration mechanisms. Also, the problem of existing solutions is the lack of consideration of the heterogeneous structure of VSDDC – the simultaneous functioning of several types of hypervisors within their framework, which differ primarily in live migration algorithms.

The aim of the work is to increase the efficiency of using VSDDC resources with a heterogeneous structure through the development of mathematical and software for the relocation of virtual machines.

3. MATHEMATICAL SUPPORT FOR THE VM REALLOATION PROCESS IN VSDDC

As part of solving the problem of mathematical support for the process of VM reallocation in VSDDC, a simulation of virtualized VSDDC resources was performed. Vector algebra was chosen as the methodological basis for modelling, in particular, a multidimensional vector representation of the availability, allocation (utilization) and requests for the use of virtualized resources. So, on a set of physical machines (PM) VSDDC $F=\left\{F_1,F_2,...,F_k\right\}$, a set $R=\left\{R_1, R_2,...,R_d\right\}$ is defined, where d is the number of types of computing and communication resources (CCR). Then the CCR of the element $F_i \in F$ can be represented by a d-dimensional vector of their completeness $P_i=\left\langle P_i^1,...P_i^m,...,P_i^d\right\rangle$,, where P_i^m is the completeness of the m-th type of resource $R_m \in R$, which the element $F_i \in F$ assumes.

The set $V=\left\{v_1,v_2,...,v_n\right\}$ of VMs operated by VSDDC users is also defined. Then the need $v_j \in V$ for an m-type resource from an element can be represented by a d-dimensional request vector $D_j=\left\langle D_j^1,...D_j^m,...,D_j^d\right\rangle$, where the request D_j^m is an m-type CCR element $v_j \in V$, and the use of CCR can be represented by a d–dimensional resource allocation vector $U_i=\left\langle U_i^1,...U_i^k,...,U_i^d\right\rangle$.

During development, it was necessary to reduce the dimension of the vector space of virtualized CCR due to its three–dimensional representation, relative to the basic virtualized resources (C – VCPU, M – RAM, N - bandwidth of the telecommunication channel used for VM migration).

An approach has been chosen to represent the vector space CR in the form of a Normalized Resource Cube (NRC), on which the vectors are determined: resource availability (VRA_1), resource allocation (VRA_2), resource request by an element (VRR_1) VRR_{1,v_n}. In this case, the vector difference between the vectors VRA_1 and VRA_2 determines the vector of remaining resources (VRR_2). Also, on the basis of these vectors, the resource imbalance vector (VRI) was determined – the vector difference of projections on the VRA_1 and VRA_2 (Figure 1) $VRI=(\hat{C}-\Delta)+(\hat{M}-\Delta)+(\hat{N}-\Delta)$, where $\Delta = \frac{VRA_1}{3}$. Then, to select a VM to be placed on a specific PM, one should consider such an element $v_n \in V$ that reduces the magnitude of the vector $VRI'=\sqrt{(C-\Delta)^2+(M-\Delta)^2+(N-\Delta)^2}$.

The virtualized CCR model has been supplemented by taking into account the allocation of CCR to VM live migration algorithms. The analysis of live migration algorithms, as well as research in the field of modelling the VM live migration process, allowed us to determine the value of overhead costs for live migration.

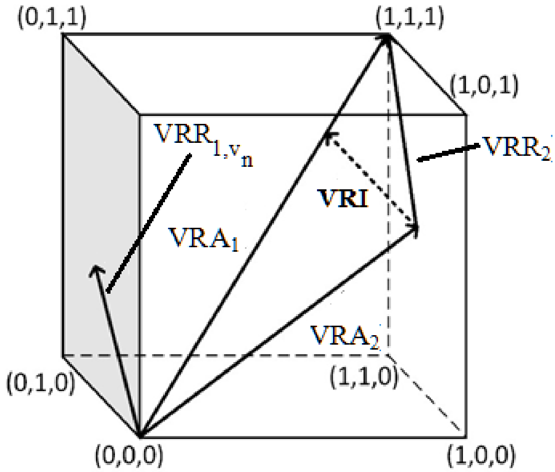

Figure 1. The view of the NRC and the corresponding vectors

Thus, the solution of the VM reallocation problem, taking into account the overhead introduced by specific live migration algorithms used in VSDDC with a heterogeneous structure, can be defined as a combinatorial optimization problem associated with a decrease in the value of the VDR vector, which sets the equilibrium value of C, M and N dimensions of the normalized resource cube.

4. ALGORITHMIZATION OF THE SOLUTION OF THE REALLOCATION PROBLEM

As part of solving the problem of VM repositioning, taking into account the overhead introduced by specific live migration algorithms used in VSDDC with a heterogeneous structure, well-known implementations of VM repositioning mechanisms were investigated, such as: the planar hexagon method, the vector point method and the method for calculating the load of a virtualized server [6]. A number of these implementations were later considered as alternatives for a comparative evaluation of the developed VM reallocation algorithm.

The metaheuristics of Ant Colony Optimization (ACO) [7] was chosen to solve the problem of VM over exposition as a multidimensional vector combinatorial optimization problem. A variant of the ACS (Ant Colony System) algorithm has been selected to develop a VM reallocation algorithm. The developed VM reallocation algorithm provides a VM migration matrix, which differs from the known ones by taking into account the heterogeneous SDDC structure and additional resources required by live migration algorithms when calculating it.

In contrast to the classical ACS algorithm, which is focused on solving the problem of finding the shortest path, in the modified VM reassignment algorithm, instead of the value of the distance between the route points, it is proposed to use the value of the value of the VDR vector: the smaller this value is when choosing a specific VM, the more preferable its choice is.

At the same time, as in the classical ACS algorithm, an artificial brain (AB) is used as the unit solving the problem of local optimization. Based on the obtained local solutions of the subset, a global solution is formed by them $\tilde{s}$.

In the developed algorithm, the migration matrix $MM_{i,j}$ is used as an element of the local solution s of the generalized AES algorithm, in an operational form represented by the expression:

$$MM_{i,j} = \begin{cases} 1, \text{ if } v_i \rightarrow F_j \\ 0, \text{ otherwise} \end{cases} \tag{1}$$

and the element of the resulting (global) solution $\tilde{s}$ is the matrix MM_G.

Having defined the overhead costs of live migration as $HP_{MM_{i,j}}$, the objective function f, which ensures obtaining the optimal local solution s by an individual artificial ant, is defined as maximizing the ratio:

$$\max f(MM_{i,j}) = \frac{N_{F_{HA}}}{HP_{MM_{i,j}}}, \tag{2}$$

where $N_{F_{HA}}$ is the number of inactive PM ($F_{HA} \subset F$). The physical meaning of the objective function can be interpreted as an increase in the number of PM to which no VM is allocated and which can be excluded from the SDDC power consumption scheme and/or used for a new VM cycle. The objective function $\tilde{s}$ of the global solution is defined as:

$$\max f(MM_G) = \frac{N_{F_{HA}}}{HP_{MM_G}} \tag{3}$$

Unlike the classical ACS algorithm, the initial stage of the developed algorithm is the formation of homogeneous subsets F^g based on a heterogeneous set PM F, where t is the number identifying the type of CPU (CP) (for example, Xen=1, KVM=2, etc.). The procedures of the developed VM reallocation algorithm considered below are applied in parallel to the elements of each of the subsets F^g. The scheme of the algorithm for the formation of homogeneous subsets F^g is shown in Figure 2.

Also, unlike the classical ACS algorithm, where the pheromone level value τ_{ij} determines the weight of an edge on the path graph, in the developed VM repositioning algorithm, the pheromone level value $\tau(t)$ at the t-th step is set by a $n \times m$ dimension matrix, where n and m are, respectively, the powers of the sets V and F.

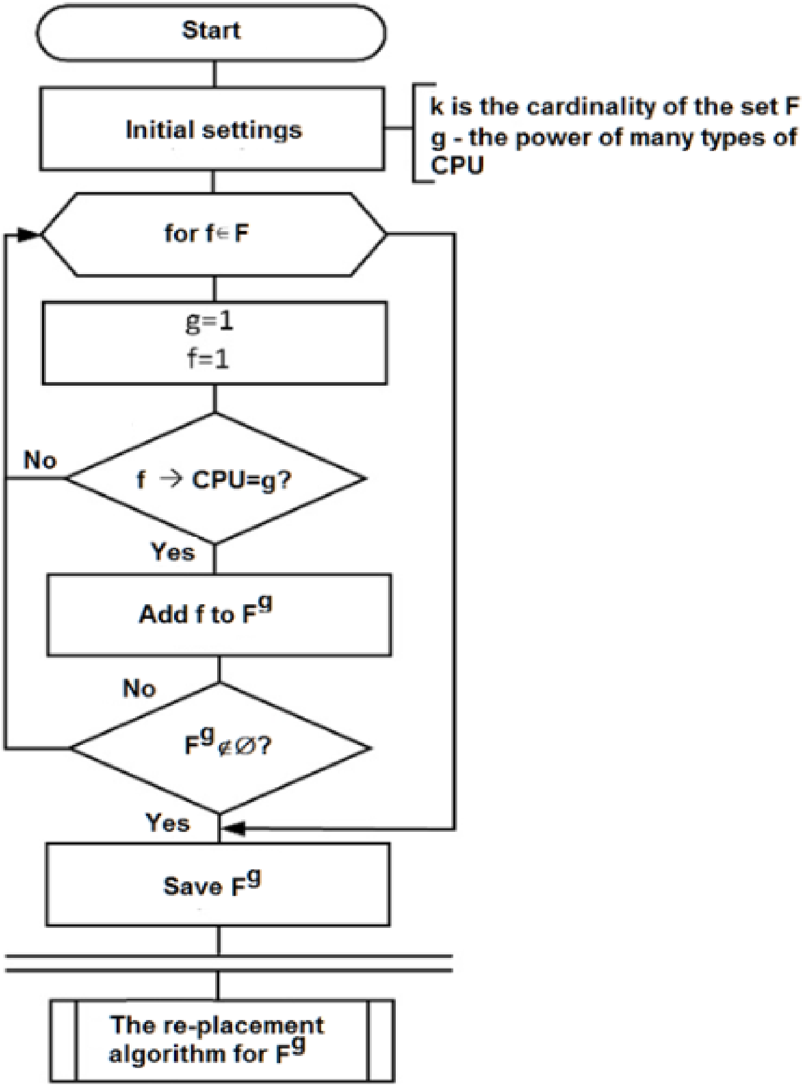

Figure 2. Diagram of the algorithm for the formation of homogeneous subsets F^g

5. ARCHITECTURE OF A SOFTWARE-IMPLEMENTED DISTRIBUTED VM RELOCATION SUPPORT SYSTEM IN VSDDC WITH A HETEROGENEOUS STRUCTURE

The architecture of a distributed VM relocation support system based on the "manager-agent" paradigm is shown in Figure 3.

The implementation of the presented modules is carried out in the PySincObj framework, designed for the development of distributed systems and having appropriate APIs to existing monitoring systems.

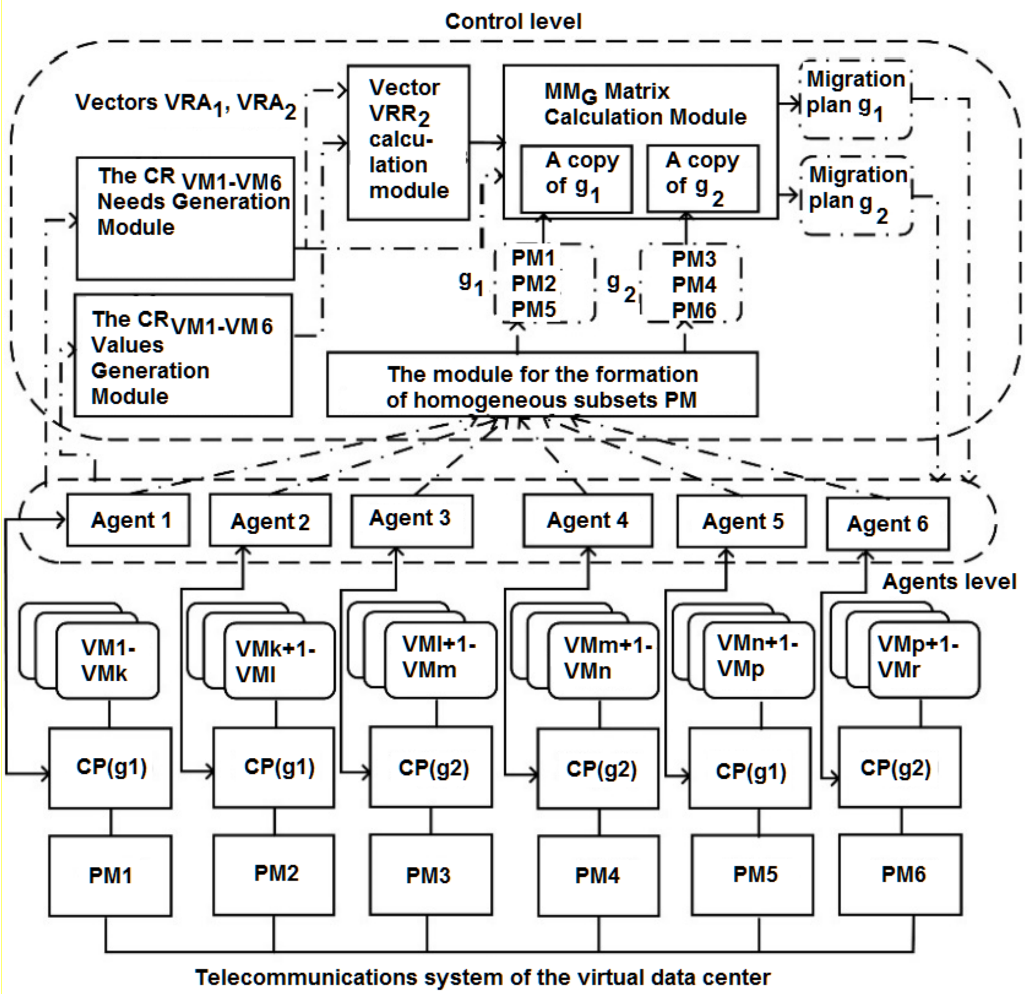

Figure 3. The architecture of a distributed VM relocation support system based on the "manager-agent" paradigm.

6. MODELING

To assess the degree of achievement of the research goal, it was decided to conduct a simulation experiment. The AnyLogic simulator [8] was chosen as the simulation environment.

Within the framework of the developed simulation model, a comparative simulation experiment was planned to evaluate the result of converting VM to VSDDC with different structure and degree of heterogeneity [9] for:

- the developed algorithm for repositioning the VM;
- SSP - XenSandPiper algorithm [10] (works only on homogeneous SDDC with CP type Xen);
- VSL - VirtualizedServerLoad algorithm [11] (functions only on homogeneous SDC with CP type KVM).

An example of averaged results over 10 runs of the simulation model for randomly generated VSDDC parameters and a fixed value of the VSDDC heterogeneity coefficient (ratios PM with CP Xen and CP KVM), where 0 is a completely homogeneous VSDDC with PM based on Xen, and 0.5 is the most heterogeneous VSDDC (50 CP based on Xen, 50 CP KVM) are presented in Figure 4.

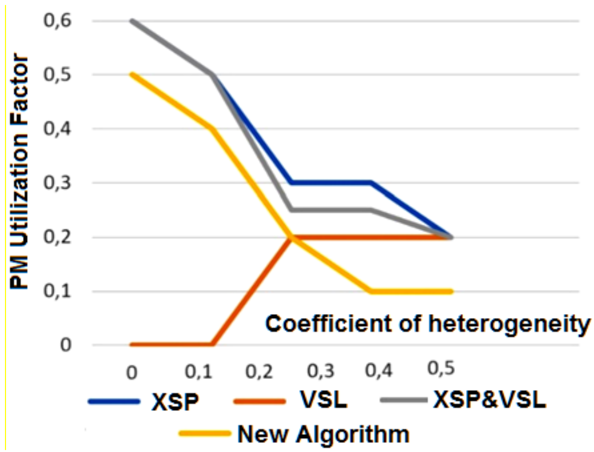

Figure 4. An example of the average results of a simulation experiment.

7. CONCLUSION

The following results were obtained:

1. A model of multidimensional representation of virtualized resources has been developed, which takes into account the normalized value of their use by live migration algorithms and provides the possibility of calculating their imbalance, which determines the need to perform the process of reallocation of virtual machines.

2. An algorithm for repositioning virtual machines has been developed based on a reasonably chosen method for solving the problem of multidimensional combinatorial optimization.

3. The architecture of a software-implemented support system for the relocation of virtual machines in VSDDC with a heterogeneous structure has been developed.

4. An experimental study was conducted to evaluate the efficiency of using VSDDC resources based on the proposed algorithm for solving the VM reallocation problem for various variants of the VSDDC structure and the virtual machines running on it

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