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Optimizing the Migration of Virtual Machines in Cloud Data Centers

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ABSTRACT

Dynamic resource allocation of cloud data centers is implemented with the use of virtual machine migration. Selected virtual machines (VM) should be migrated on appropriate destination servers. This is a critical step and should be performed according to several criteria. It is proposed to use the criteria of minimum resource wastage and service-level agreement violation. The optimization problem of the VM placement according to two criteria is formulated, which is equivalent to the well-known main assignment problem in terms of the structure, necessary conditions, and the nature of variables. It is suggested to use the Hungarian method or to reduce the problem to a closed transport problem. This allows the exact solution to be obtained in real time. Simulation has shown that the proposed approach outperforms widely-used bin-packing heuristics in both criteria.

KEYWORDS

Assignment Problem, BFD, Cloud Data Centers, CloudSimFFD, Migration, Multi-Criteria Optimization, Optimal Placement, Transport Problem, Virtual Machines, Virtualization

INTRODUCTION

There are increasing demands on the data center resources due to the growth of Internet traffic, the emergence of “big data”, the development and spread of cloud services and artificial intelligence systems. Data centers must provide sufficient resources to hosted applications, which workload can vary significantly over time.

In order to avoid performance degradation, dynamic reallocation of resources is used. In cloud data centers, resource allocation is performed by moving virtual machines (VM) between physical servers. This process is called virtual machine migration. If the migration occurs without interruption of the VM, then this migration is called “live”. Such migration allows data centers to guarantee service level agreements (SLAs), balance the load between physical machines (PM), and host VMs on fewer PMs to improve overall resource utilization and reduce resource wastage. Servers released by this process can be turned to lower power states (such as suspended or turned off) with the goal of minimizing the overall power consumption.

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In addition, information resources can be redistributed between different data centers in accordance with the resource demand, for example, due to time zones. This makes us look for efficient and fast algorithms for resource allocation, taking into account the growing dimensions of problems.

This paper is devoted to the development of an effective algorithm for placing virtual machines selected for migration on physical servers. The process of dynamic resource allocation includes three stages: monitoring servers for detecting critical situations, VM selection for migration and destination server selection (Xu, & Fortes, 2011; Beloglazov, & Buyya, 2012)

This paper focuses on the third stage: destination server selection for hosting virtual machines. The problem of multi-criteria optimization is set and the method to find the solution is chosen.

The main contributions of this paper are the following.

1. Formal definition of multi-criteria optimization of virtual machine placement in the form of assignment problem.
2. Proposed methods allowed to find exact solution of the VM placement problem in real time and significantly increase its dimension.
3. Competitive analysis of proposed solution with the First Fit Decreasing (FFD), Best Fit Decreasing (BFD) heuristics based on simulation evaluation.

This paper is an extended version of the conference paper presented at the 28th Conference of Open Innovations Association (FRUCT) (Toutov et al., 2021). It has been significantly expanded and deepened in the following areas.

1. The paper presents the results of large-scale simulation with a real workload traces using the CloudSim toolkit. It is shown that the efficiency of proposed virtual machine placement method can be several times greater compared to the FFD algorithm by the combined ESV metric (energy consumption and violations of SLA agreements).
2. Additional experiments were carried out to compare the Hungarian method and the Simplex method in relation to solving VM placement problem.
3. Restrictions on the processor and memory resources of physical servers are added to the problem statement and an algorithm for taking them into account is proposed. In the initial statement, it was assumed that all physical servers could host any virtual machine.

RELATED WORKS

Nowadays, IaaS providers mostly rely on either static VM provisioning policies, which allocate a fixed set of physical resources to VMs using bin-packing algorithms, or dynamic policies, capable of handling load variations through live VM migrations. These policies can either be reactive or proactive, and typically rely on knowledge of VM resource requirements, either user-supplied or estimated using monitoring data and forecasting (Buyya et al., 2018). These approaches can be applied together and included in the main work cycle on resource management in cloud data center (Toutov, 2018).

The authors of Xu and Fortes (2010), Vorozhtsov et al. (2015) Camati et al. (2014); Ferdaus et.al (2014) considered static VM placement using bin-packing or knapsack statements of VM placement problem. These problems belong to the class of NP-hard problems. Therefore, in practice greedy heuristics such as FFD, BFD and their modifications are widely used for destination server selection to place migrating VMs (Beloglazov, & Buyya, 2012; Gulati et al., Zhu, 2012; Moges, & Abebe, 2019, Alhammadi, & Vasanthi, 2021). However, as VM consolidation is a NP-hard problem, greedy approaches are not guaranteed to generate near optimal solutions.

Recently, Ant Colony Optimization (ACO) metaheuristics and genetic algorithms have been used to address bin packing problem and VM consolidation (Xu, & Fortes, 2011; Ferdaus et al., 2014, Feller et al., 2011, Gao et al., 2013, Lu et al., 2021, Saxena et al., 2021). Virtual machine placement