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Clustering based virtual machines placement in distributed cloud computing

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HIGHLIGHTS

- A clustering based algorithm is recommended for data center selection problem.
- It is more applicable to large scale VM placement and runs faster.
- A more effective VM partition algorithm is presented utilizing a new model of VMs.
- All algorithms can address both homogeneous and heterogeneous requirements of VMs.

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ABSTRACT

Resource virtualization is one of the most prominent characteristics of cloud computing. The placement of virtual machines (VMs) in the physical machines determines the resource utilization efficiency and service quality. Especially for distributed cloud computing, where the data centers (DCs) span a large number of geographical areas and all DCs are connected by high speed internet, the placement of VMs of one big task or of one organization focuses on minimizing the distances and bandwidths between DCs. This minimizes communication latency and improves availability. A data center cluster should be found firstly to accommodate the requested VMs. The purpose is to minimize the maximum inter-DC distance. In contrast to existing method that only considers the distances between data centers, a more efficient clustering based 2-approximation algorithm is developed by taking full use of the topology and the density property of cloud network. The simulation shows the proposed algorithm is especially appropriate for very large scale problems. Then, the requested VMs should be partitioned to the DC cluster, so that the expensive inter-DC bandwidth is saved and the availability is improved. With the introduction of a half communication model, a novel heuristic algorithm which further cuts down the used bandwidths is presented to partition VMs. Its time complexity is reduced to $O(n^2)$ by a factor of $O(logn)$ and it runs 3 times faster than the existing method.

1. Introduction

Cloud computing has gained great popularity in recent years for the efficient resource usage and convenient service access [1, 2]. These competitive powers are attributable to the introduction of virtual technology and distributed networking of cloud. Based on the actual standard of virtualization industry, the cores of physical machines (PMs) can be virtualized into more virtual CPUs (vCPUs) [3]. Virtual machines (VMs) can be placed on the granularity of vCPUs and thus gain a more efficient resource utilization. It is also hoped VMs can be deployed closer to the end users in different geographical locations by distributed networking. Distributed cloud consists of a lot of data centers (DCs) and all DCs are connected by high speed internet [4]. Contrary to the counterparts of centralized cloud, distributed DCs have relatively small capability because they are planned according to the less traffic of the dispersed area they locate.

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As more small cloud service providers enter cloud market, DC becomes much smaller [5]. But the distribution scheme has several benefits. The sites of DCs are selected according to the principle of proximity. Services of end users can be completed in the DC nearer to them. The reaction time is shortened and the overall long-distance bandwidth consumption is cut down. This means the service latency is reduced and availability is increased. Moreover, relatively small DC can be easily retreated/added based on the services traffic change in different areas. So distributed cloud is more scalable and more elastic. It has become the mainstream.

The VMs of some applications may span more than one DC for the relatively small capacity of DCs or some availability policy where an upper limit for the VMs in one DC is designated [6]. Most of such applications are geo-distributed in nature and can benefit from the utilization multiple DCs. One example is a big data stream processing system on a cloud for a huge supermarket chain across regions [7]. The processing systems consist of a large number of independent tasks. Because various data, such as information of customers and sales are produced continuously in different regions, the VMs to process the data and tasks are also distributed naturally. The VMs can be deployed in any DCs without violating the forced task semantics. The data stream will consume huge inter-DC bandwidth. Other applications, such as the thousands of virtual desktops (they are also a kind of VMs) for all branches of companies [8,9], processing-intensive tasks where the input of one processor is from another processor in another area [5,10] and logistic information systems [11], also need to span more than one DCs. Distributed cloud is the most eligible candidate.

We should select such a DC cluster firstly to accommodate the requested VMs which dedicate to one application and communicate with each other. In addition to the consideration of capacity matching, the inter-DC distance should be as small as possible to reduce the service latency. The primary objective is to minimize the maximum inter-DC distance. This prevents from the possibility of tasks running in VMs which are very far apart, so as not to delay the overall completion time of the user application [6].

After DC cluster is selected VMs should be partitioned to each DC of the cluster. On one side, the partition should not exceed the upper bound of DC capacity. On the other side, the important resource: network bandwidth between different DCs should be minimized [12]. This is because of two reasons: (1) Economical consideration. The long-distance line between DCs is very expensive. (2) Availability consideration. The more the long-distance line is used, the lower availability is possible. VMs with larger traffic can be agglomerated in one DC so that as many communications are completed inside the DC as possible.

This paper aims to investigate more efficient algorithms for the aforementioned data center selection and VM partition problems. The main contributions are summarized as follows:

1. A novel clustering based algorithm is recommended for data center selection problem. In addition to distance, this algorithm fully takes into consideration other networking information of cloud, such as topology, density integrated with DC capacity and thus improves the efficiency. The execution time is shortened 15%–27% for the random distribution scenario of DCs and 15%–72% for the clustering scenario respectively. Furthermore, it is more applicable to large scale VM placement.
2. With introduction of half communication model of VMs, the overall traffic of a VM can be considered in the decision process. Therefore, a new slightly more effective VM partition algorithm is presented. Its time complexity is reduced to $O(n^2)$ by a factor of $O(\log n)$ and the efficiency is improved about 4 times.
3. The two algorithms are designed on the basis of the actual standard of virtualization industry, i.e., the granularity of vCPUs. They can address both homogeneous and heterogeneous requirements of VMs.

The rest of this paper is organized as follows. Section 2 discusses related work. Section 3 addresses the DC selection problem by means of a clustering based method and proves it as 2-approximation. Section 4 defines the half communication model of VMs and then presents a new faster algorithm. Section 5 introduces the test environment and evaluates both methods, especially on the algorithm efficiency. Finally the whole paper is wrapped up in Section 6 with some future work.

2. Related work

2.1. VM placement and current virtualization standard

Efficient resource usage lays the foundation for the service level assurance and thus makes the cloud service provider business a success and of maximum profitability. So the resource allocation problem is a key challenge for cloud computing [13,14]. Various aspects of resource allocation are explored, such as server integration [15], load balance [16] and energy [17]. But all these papers mainly concentrate on memory and CPU resources. DC selection and bandwidth saving are seldom studied in past years. The placement of VMs in one DC based on the traffic matrix is investigated in [18,19] and the objective is to improve the scalability of DCs.

Different models are adopted to address the challenge. Bin packing [20,21] and graph theory [18,22,23] are two models widely used and they are selected based on the granularity of resources. The former assumes resource can be split arbitrarily to adapt to the diverse resource requirements of VMs. Statistical multiplexing is often utilized to compact more VMs into one PM. But it is not realistic for the current virtualization techniques. The resource can only be refined to the granularity of vCPUs [24]. Even VMWare, one of the leading virtualization technology corporations, claims that for its latest virtualization product: VMware vSphere 5.x, a virtual machine cannot have more vCPUs than the number of logical cores of the host. The number of logical cores is equal to the number if hyperthreading is disabled or at most twice of that number of the physical cores if hyperthreading is enabled [3]. The number of logical cores is just the most number of VMs that can be hosted in the PMs. In the VM instance types provided by Amazon, vCPU is used as the computing resource metric and it varies from 1 to 32 [25]. On the other side, bin packing based algorithm assumes the items have no relationship and fails to describe the situation when the packed VMs communicate with each other [26]. So we use the graph theory based model. Resource unit "slots" is often integrated with it [18,22,23]. The number of slots can be determined by some existing capacity tools [18]. Herein each slot corresponds to a vCPU. One slot can only be occupied by one VM. But one VM may require more than one slot.

Data center selection problem is firstly explored in [6]. After formulating as minimizing the diameter of a complete vertex weighted graph, the problem is proved as NP-hard. A FindMinStar algorithm is recommended to find a DC cluster around a certain DC and to calculate the corresponding diameter. Then in a 2-approximation algorithm MinDiameterGraph, FindMinStar is invoked for each DC. All the corresponding diameters are calculated and compared straight-forward. The DC cluster with the minimum diameter is selected as the solution. The time complexity of MinDiameterGraph is $O(n^3)$ and it is dominated by FindMinStar algorithm with time complexity $O(n^2)$. For the VM partition problem, a heuristic algorithm with $O(n^2 \log n)$ time complexity is also presented [6]. The simulation shows the method can produce better result than a random and a greedy algorithm.

But the paper assumes the DC capacity is measured by the number of VMs, so the algorithms can only address the homogeneous situation where all VMs require the same amount of resource. Moreover, normally the VM placement is online. It is necessary to explore lighter-weight algorithms.