Cost-Effective Service Provisioning for Hybrid Cloud Applications

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Abstract. A hybrid cloud, which combines a private cloud and a public cloud, has become more and more popular. For most corporations, they leverage one public cloud. However, with fierce competition among public cloud providers, public cloud services change frequently, which may lead to service unavailability and a less cost-effective hybrid cloud solution. As a result, leveraging multiple public clouds in the hybrid cloud is a potential solution. In this paper, we identify such a problem in current hybrid cloud and analyze the necessity of load balancing for hybrid cloud applications. Focusing on cost minimization and performance guarantee, we propose a Least Cost per Connection (LCC) algorithm so as to choose the most cost-effective clouds along with adapting changes among multiple public clouds. The simulation results show that our solution can significantly decrease the outsourcing cost as well as guarantee QoS of applications.

Key words: hybrid cloud, multi-cloud, cost-effective

1 Introduction

A hybrid cloud, which combines a private cloud and a public cloud, has become more and more popular. The state of the cloud report from RightScale points out that, among all the enterprise respondents, 55% of them expect to use hybrid clouds [1].

However, for most corporations, they deploy their applications on single public cloud. First, cloud computing platforms sometime breakdown and update bug, which may influence their business. Second, cloud providers offer discount to attract users and occupy cloud computing market. For example, the price of AWS drops 12 times in 2013 while Google Compute Engine [2] made a cumulative reduction of 38 percent in prices from January to October in 2014. When the price drops, deploying applications in single cloud makes it difficult to switch to other providers for lower price. Third, since more corporations join in the cloud

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market, cloud users are willing to avoid provider lock-in. As a result, deploying applications in multiple public clouds can contribute to obtaining a more cost-effective and stable hybrid cloud solution.

When leveraging multiple public clouds, we face the following challenges. First, since cloud users can leverage multiple clouds, it is challenging to distribute workloads among private and public clouds so as to obtain a cost-effective solution. Second, as cloud computing platforms sometime breakdown or update, it may lead to service unavailability or performance degradation. Such maintenance makes it more difficult to derive a cost-effective solution. Third, cloud computing price changes with time. Cloud users always want to use the most cost-effective cloud products. Deploying applications on unsuitable cloud products may cost more money and make applications inefficient.

To address these problems, we propose a cost-effective service for hybrid cloud applications, which selects the best public cloud for out-sourcing and adapts cloud price changes dynamically, along with provisioning global load balancing. The system uses a two-tier load balancing mechanism, provisioning virtual machine (VM) and cloud level load balancing. The system firstly chooses the best instance on each cloud for certain applications using CloudCmp [5] tools. Then the system uses the proposed Least Connection per Cost (LCC) algorithm to distribute job requests among public clouds. At last, the system scales up or down automatically according to the price and performance of each cloud.

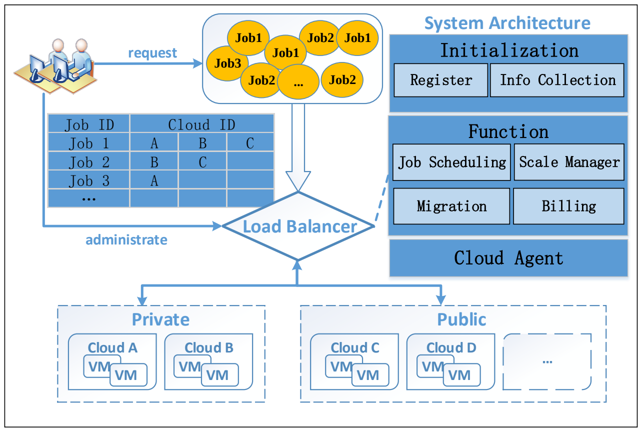
The remainder of this paper is organized as follows. In Sec. 2, we introduce the system architecture and design objectives. Sec. 3 provides detailed description of implementation principles and proposes LCC job scheduling algorithm. Sec. 4 introduces a series of simulation experiments to test our system functions and performance. Sec. 5 provides an overview of related work. Finally, we conclude our paper and provide future works in Sec. 6.

2 Design Objectives

This system is designed to help the hybrid cloud users provision cost-effective services, especially for those who deploy multiple public clouds. Based on the fact that different types of applications require different computing resources, we classify all the applications into three representative types roughly:

* *CPU-intensive application.* In these applications, CPU resource is more eagerly needed than other computing resource. For example video processing, scientific computing and so on.
* *Memory-intensive application.* High IO throughput application such as large Map-Reduce tasks which depend on sufficient memory for data shuffling.
* *Disk-intensive application.* NoSQL database (e.g., Cassandra, MongoDB) or Distributed File System (e.g., HDFS) have high demand on storage.

Our design prefers processing workloads in the private cloud, and outsources excessive workloads to the public clouds. Since prices and performance of public clouds vary from cloud providers, we need to maintain high quality services as well as save cost. Before the load balance system start working, we select the most suitable type of instances on each cloud in advance for the application. Since Li *et al.* [5] compare VMs of multiple cloud providers so as to find out which are the most suitable.



Job ID	Cloud ID		
Job 1	A	B	C
Job 2	B	C	
Job 3	A		
...			

Fig. 1. Overview of load balance system design for a hybrid cloud.

Fig. 1 shows an overview of load balance system design for hybrid cloud applications. First, cloud users need to register their applications on the load balancer with a unique application id and provide detailed information of requested resource. Second, through administrating an application-cloud mapping table, the system selectively adds a private cloud and public clouds for certain applications.We deploy the application with cloud agent and generate a virtual machine template on the most suitable instance type. Cloud agent starts to collect and feedback the cloud load information to load balancer periodically.

The load balancer receives feedbacks and updates the priority of each cloud based on our load balance algorithm. Here the cycle length depends on the job requests arrival frequency. When the load balancer receives a batch of job requests, it checks the priority of each cloud and dispatches the job requests to the most cost-effective clouds.

Cost-Effective. Due to the unpredictable workloads, it's hard for a private cloud to predict an exact amount of hardware resources. As such, the private cloud is not capable of processing such immense workloads, and the public clouds can satisfy the requirements of high capacity and scalability. Considering the variety of cloud providers, users want to add or remove a cloud for their applications freely. When users deploy their applications on multiple clouds, how to choose the most cost-effective clouds becomes a critical problem.

In this paper, how much a job request costs is taken as the measurement of cost-effectiveness (CE ratio for short). For example, if the price of a VM of a cloud provider is P, and the VM can process N job requests per second, the CE ratio equals $\frac{P}{N}$. The number N is hard to figure out through calculation, so we use measurement tools of Cloudcmp to monitor it.

Flexibility. With rapid development of cloud computing market, services provisioned by public cloud providers change quite frequently. As such, cloud users need to change their strategies of leveraging public clouds.

In order to achieve this goal, the design of the system is guided by the asynchronous message-driven paradigm through RESTful design principle. We use RESTful API to reduce the interdependency of tightly coupled interfaces, generally lowering the complexity of integration.

Specifically, the System allows cloud users to choose on which clouds to deploy their applications, which leads to a many-to-many relationship.

Global Load Balance. Users' applications are deployed on multiple clouds. As such, we need to ensure global load balancing, so as to provision cost-effective services and make the best use of cloud resources we've bought.

Since load information collected from other clouds is transmitted via the Internet, the transmit latency must be low. We use short TCP connections for immediate reinforcement. To reduce the number of messages, we abstract a cloud as an unit to distribute workloads among clouds. For load balancing among VMs, each cloud can address it. The low-level quality of service is guaranteed by the service level agreement of cloud providers.

3 System Model

In this section we specifically describe how this system scheduling jobs and leveraging the auto scaling service for resource reallocation.

Job Scheduling & Resource Allocation Decoupling. Job scheduling and resource allocation are the two main tasks of load balancing. Job scheduling is highly required on bandwidth delay, while resource allocation is closely related to cost. Based on the characteristics of two different tasks, we discrete the job scheduling module and resource management module from logic view. Specifically, the job scheduling module only takes responsibility of receiving and dispatching job requests while resource allocation module takes charge of monitoring the cloud resource usage and decides on when to scale up or down.

Cloud-level Load Balancing & VM-level Load Balancing Decoupling. In our system, we adopt a two-level hierarchical load balancing architecture, i.e., a cloud level and a VM level. On the cloud level, we take the cloud as an unit of scheduling object as shown in Fig. 1. On the VM level, we use cloud back-end load balancing services for job distribution among VMs. Almost all the public cloud providers provision load balancing services within their clouds. For example, Openstack [6] integrates LBaaS (Load-Balancing-as-a-Service) into Neutron component. LBaaS allows cloud users to scale their applications, detect unhealthy VM instances, balance loads across regions, route traffic to the closest VM and so on.

Centralized Management. Cloud agent is used to sent cloud information back to the load balancer. We add a heartbeat mechanism to report the cloud health status periodically.

3.1 Algorithm

Cloud Ability Measurement. Here we consider two sets of cloud resources, i.e., PUB and PRI. Let PUB be the set of public clouds, which is denoted as $\{u_1$, u_2, ..., $u_m\}$. Moreover, let PRI be the set of the private cloud, which is denoted as $\{r_1, r_2, ..., r_n\}$. Furthermore, we set the resource parameters{cpu, mem, disk, net}.

$$M_i(t) = \min\{\frac{\lambda_i^{CPU}(t)}{d_i^{CPU}}, \frac{\lambda_i^{MEM}(t)}{d_i^{MEM}}, \frac{\lambda_i^{DISK}(t)}{d_i^{DISK}}, \frac{\lambda_i^{NET}(t)}{d_i^{NET}}\} \tag{1}$$

Algorithm 1 Least Connection-Cost Ratio Scheduling (LCC)

```
Denote (key,index) as cloud type and cloud ID
for each time slot $t \in [0, 1, 2, ...]$ do
  $key = 0$
  for each cloud $r_i \in PRI$ do
    if $r_i$ is not alarmed then
      set $key = 1$
      calculate cloud priority $\eta_i$
    end if
  end for
  set $index$ the private cloud ID with max priority
  for each cloud $u_i \in PUB$ do
    if $u_i$ is not alarmed then
      calculate cloud priority $\eta_i$
    end if
  end for
  set $index$ the public cloud ID with max priority
  for each job $J_i(t) \in [J_1(t), J_2(t), ...$ do
    if $key$ Equals 0 then
      Dispatch the job $J_i(t)$ to cloud $u_{index}$
    else
      Dispatch the job $J_i(t)$ to cloud $r_{index}$
    end if
  end for
end for
```

Equation (1) figures out the job request service rate of each VM in a cloud.

Job Scheduling We denote the current number of connections on each cloud as $C_i(t)$. And the price of selected instance on each cloud is denoted by $P_i(t)$. Furthermore, the value of priority of each cloud is denoted as $\eta_i(t)$.

$$\eta_i(t) = \frac{M_i(t) - C_i(t)}{P_i(t)} \tag{2}$$

We sort the priority obtained based on Equation (2) of each cloud, and record the priority list in configuration files. When a job request arrives, the load balancer will select the cloud which has the maximum priority to server the request. If the heartbeat packet from the preferred cloud does not arrive in time, the preferred cloud will be the second one. The detailed algorithm is described as Algorithm 1.

Cloud Scaling We set two thresholds for scaling up and down with a lower bound and an upper bound, denoted as σ_l and σ_u, respectively.

$$\sigma_i(t) = max\{\frac{\lambda_i^{CPU}(t) - \sum_{n=1}^{N(t)} d_{in}^{CPU}}{\lambda_i^{CPU}(t)}, \frac{\lambda_i^{NET}(t) - \sum_{n=1}^{N(t)} d_{in}^{NET}}{\lambda_i^{NET}(t)}, \frac{\lambda_i^{MEM}(t) - \sum_{n=1}^{N(t)} d_{in}^{MEM}}{\lambda_i^{MEM}(t)}, \frac{\lambda_i^{DISK}(t) - \sum_{n=1}^{N(t)} d_{in}^{DISK}}{\lambda_i^{DISK}(t)}\} \tag{3}$$

Algorithm 2 Cost-Effective Resource Allocation

```
set $upscale = true$, $downscale = false$
for each time slot $t \in [0, 1, 2, ...]$ do
    for $\lambda_i \in PUB$ do
        if $\sigma_i(t) \leq \sigma_u$ then
            $upscale = false$
        end if
        if $\sigma_i(t) \leq \sigma_l$ then
            $downscale = true$
        end if
    end for
end for
if $upscale$ is true then
    send $scale - up$ direction to the prior cloud
end if
if $downscale$ is true then
    send $scale - down$ direction to the worst cloud
end if
```

We use Equation (2) to calculate the priorities of public clouds. Here, we use Equation (3) to get the resource usage of the current cloud in simulation experiments. During each time slot, the load balancer checks whether each cloud needs to adjust its scale. In real world, cloud provider provisions API to get the states of cloud resources, which is much preciser. Algorithm 2 describes the resource allocation process.

4 Experiment

In this section, we conducted a series of simulation experiments from differen-t perspectives. The results demonstrate that our load balance mechanism for hybrid cloud application could reach cost-effective, meanwhile it also provides information on the pros and cons.

4.1 Data Preparation

Requests: We first construct the realistic job requests according to the data traces obtained from Google data center, which include the job arrive/leave time and resource cost information. Then we simulate another three specific application requests which have high demand on CPU, memory, and disk respectively.

Clouds: As the requests vary in Google trace, request should be sent to the suitable cloud for handling. So using multiple public cloud is better than single public cloud. As an instance's startup need some delay, using multi-cloud can somehow reduce the delay. We use three public clouds and two private clouds to construct a hybrid cloud. The parameters of each instance on each cloud is set according to the typical instance types of Amazon EC2 and Google Computing Engine.

We list the public cloud parameters set in Table. 1. We also list the resource demand of the three job requests used in experiment in Table. 2.

Table 1. Parameters of Public Clouds

Cloud ID	CPU	MEM	DISK	Price
Cloud 1	8	8	20	0.628
Cloud 2	2	8	20	0.375
Cloud 3	2	3	80	0.453

Table 2. Requirement of Resources

APP	CPU	MEM	DISK
CPU_APP	0.65	0.2	1.5
MEM_APP	0.2	0.68	2.5
DISK_APP	0.2	0.18	4.5

4.2 Experiment Results

Function Test In this experiment, we show functions that the load balancer can reach. The system able to guarantee the private cloud resource use first, keep private cloud at a higher resource utilization. The system will choose most suitable cloud for out-sourcing according to the request type. Further more, it is responsible to the price changes keeps global load balanced.

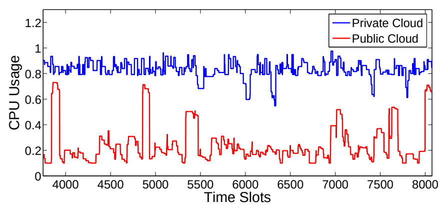


Fig. 2. CPU usage of the private and public clouds in a hybrid cloud.

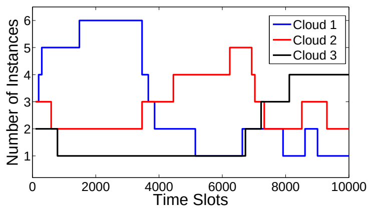


Fig. 3. Resource requirement trace of CPU-intensive, memory-intensive, and disk-intensive jobs.

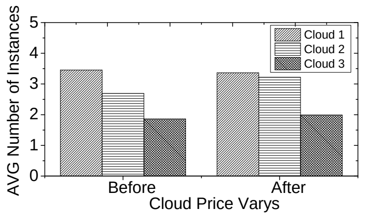


Fig. 4. The price of Cloud 1 increases 0.1 dollar while the price of Cloud 2 decreases 0.1 dollar during the optimization.

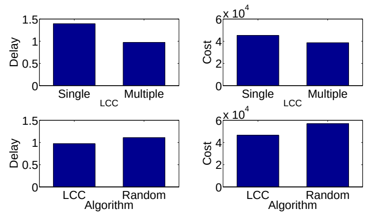


Fig. 5. Comparison test on different public clouds and comparison test between LCC and random algorithm.

Fig. 2 demonstrates respective CPU usage of the private and public clouds in a hybrid cloud. As shown in Fig. 2, the average CPU usage of VMs in the private cloud stays above 0.8 in the whole process except five short time periods. Such a phenomenon indicates that our algorithm works based on our design concept. As mentioned in Sec. 3, to maintain the least cost, we use the private cloud as much as possible while outsource excessive workloads to the public cloud. Hence, we need to ensure the average CPU usage of VMs in the private cloud stays in a range stably. Meanwhile, the average usage of VMs in the public cloud fluctuates wildly, which is led by bursty workloads. Although the workloads is bursty, the CPU usage of private cloud is stable, which further demonstrates the effectiveness of our algorithm.

Fig. 3 demonstrates the trends of the number of running VMs in three deployed clouds under different types of workloads. In the first time period, the workloads are CPU-intensive. The scale of Cloud 1 increases to the largest for it is good at processing CPU-intensive workloads. Then, when the type of workloads switch to the memory-intensive type, the scale of Cloud 1 goes down while the scale of Cloud 2 ramps up to the largest. Finally, the same trend can be observed in the third time period. As a result, our algorithm is sensitive about the changes in types of workloads and can adjust the scales of public clouds based on it.

Fig. 4 shows the scales of public clouds when their prices change. In Fig. 4, the scale of Cloud 2 increases after its price goes down. Meanwhile, when the price of Cloud 1 increases, its scale decreases a little. The effects indicate that our algorithm can adapt the price volatility and choose the cost-effective clouds adaptively.

Performance Analysis For comparisons, we use random algorithm which is most commonly used on load balance problems.

Fig. 5 plots the effects brought by different strategies of deploying the public cloud. In Fig. 5, the average delay processed by single cloud is shorter than that processed by multiple clouds. Furthermore, the cost of deploying single cloud is less than that of deploying multiple clouds. Hence, by deploying multiple public clouds, we can provision high quality services as well as saving cost. Meanwhile, to show the effectiveness of LCC, we compare LCC to a random strategy. As plotted in Fig. 5, the delay of the random strategy is longer than LCC's while the cost is more than LCC's. As a result, our algorithm works well in the hybrid cloud environment.

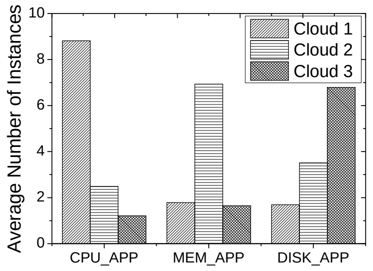


Fig. 6. The average number of instances which three applications use on three different public clouds

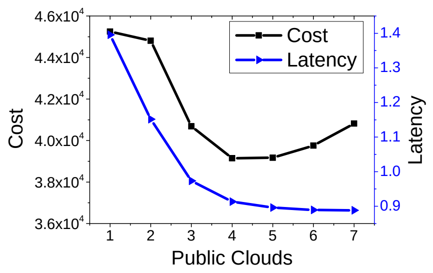


Fig. 7. Measurement on the global average cost and delay under the number of public clouds varying form 1 to 7.

Fig. 6 shows different scales of public clouds in the hybrid cloud. As shown in Fig. 3, the average number of VMs in Cloud 1 is the largest when the workloads are CPU-intensive. Then, the number in Cloud 2 is the largest when the workloads are memory-intensive while the number in Cloud 3 is the largest when the workloads are disk-intensive. Such phenomenon indicates that our algorithm is aware of the types of workloads. Furthermore, our algorithm can adjust the scales of deployed clouds based on different types of workloads and make the best use of the public clouds.

Fig. 7 plots the effects brought by different numbers of public clouds. As shown in Fig. 7, when the number of public clouds increases from 1 to 4, the values of latency and cost fall sharply. When deploying more clouds, our algorithm can adjust the respective scales as well as distribute workloads to provision cost-effective services. We have thought that the principle was "the more choices, the better", adding cloud provider only bring less cost or not, no higher. Because the load balancer can choose whether to use the cloud or not. However, when the number of public clouds increases from 4 to 7, the latency decreases slightly while the cost increases markedly. Since we need to maintain the least scale of each public cloud, deploying more clouds does not contribute to cost-saving. Furthermore, the capacity of hybrid cloud is too large to improve performance.

5 Related Work

With respect to studies on managing the performance overhead of VMs, part of the work in [10] summarizes it under diverse scenarios of the IaaS cloud. Li *et al.* in [5] focus on classifying and measuring the typical services which IaaS public clouds provide. Complementary to [10] and [5], we deal with performance issues of multiple public clouds in hybrid cloud scenarios. In terms of addressing network performance, Yi *et al.* take a close look at the unique challenges in building a network highway for big data in [9]. Complementary to [9], we consider network performance of web services when scheduling requests.

[8] gives out a hybrid cloud model which uses a workload factoring scheme to separate base workload and flash crowd workload. Furthermore, [11] models e-commerce web services and proposes an online algorithm to address the load balancing problem under flash crowds in hybrid cloud scenarios. Inspired by [11] yet different from it, we address the load balancing problem with considering multiple public clouds.

6 Conclusion

This paper proposes a Least Cost per Connection (LCC) load balancing algorithm for hybrid cloud applications, which can help provide cost-effective services. We design a system prototype for simulation experiment. The results show that our system can guarantee the private cloud usage as we expected and also achieves the goal of high performance with low cost. Compared with single cloud strategy, the cost and latency of our system decreases 30.2 and 10.1 percent respectively. This system can be integrated into hybrid cloud manage platform (CMP) like CloudForms, ManageIQ and so on. Other works we are doing now are making this system a plug-in feature into ManageIQ [12].

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