Virtual Machines Placement for Network Isolation in Clouds

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ABSTRACT
Traffic-aware Virtual Machines (VMs) placement is a key feature for cloud performance isolation. However, variability hinders a data center to provide network isolation. The existing proposals do not give an answer to a question that how we can obtain resource demand of tenants. To address it, we propose a VMs placement mechanism, which measures resource demand in a server cluster, Incubator before place VMs into a data center. By the stable matching algorithm, we consider resource availability of a data center. We show that our approach decreases cloud oversubscription, and increases link utilization through an intensive simulation.

Categories and Subject Descriptors
C.2.3 [Computer-Communication Networks]: Network Operations

General Terms
Algorithms, Performance

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Data Center Networks, VM Placement, Network Isolation

1. INTRODUCTION
Infrastructure as a Service (IaaS) provides a virtualized work space to tenants. Tenants can own a number of VMs, and shares resources on a server with the other tenants. The most significant motivation for using IaaS is a cloud data center catches both cost saving and performance guarantee. As tenants desire to maintain their services without performance interference, providing performance isolation is significant [8]. In contrast with system resources like CPU and memory, a cloud provider manages network resources by traditional best-effort manner due to the variability. However, providing network isolation is desirable to both providers and tenants. Because lasting oversubscription hinders meeting performance guarantee. Tenants may hesitate to use a cloud data center in spite of cost saving in a such case. For providers, a deserted cloud data center cannot earn high revenue.

Recently, efforts to provide network isolation by VMs placement has emerged. Wang et al. [11] address the issue by the bin packing algorithm. Breitgand et al. [3] extend the work. [3] not only reduce oversubscription probability but also minimize the number of bins, physical servers where VMs are consolidated. However, Prior work assume that overflow probability $p$, which is determined randomly, nevertheless a method to obtain resource demand is a key consideration for initial traffic-aware VMs placement. Furthermore, their simulation results show that the algorithm only reduces the number of bins, not oversubscription.

In this paper, we design a traffic-aware VMs placement mechanism based on practical traffic measurement. We measure traffic distribution in a server cluster named Incubator and place VMs into servers by the stable matching algorithm. We named a series of process as the Incubating. Our key contributions are as follows.

- Prior work assume that traffic demand is exposed or oversubscription occurs randomly, but we measure real traffic demands of tenants.
- By designing a time-variant mechanism, we catch both oversubscription reduction and high utilization.

2. RELATED WORK
We categorize prior work into two types. One is bandwidth guarantee approach [6, 8, 9, 10] that meet network isolation by a bandwidth allocation policy. The other is VMs placement approach [3, 11] that mitigate oversubscription by traffic-aware VMs placement.

Bandwidth guarantee: Seawall [10] is a fair bandwidth sharing policy among VM-pairs. It enforces fairness by ECN feedback mechanism. However, Seawall has a limitation that a tenant can obtain more bandwidth by increasing the number of destinations. Secondnet [6] is a bandwidth provisioning policy. In contrast with Seawall, Secondnet guarantees bandwidth for not each VM but tenant. However, Secondnet only provides network isolation among VMs under a single tenant. Gatekeeper [9] is an ECN feedback based mechanism, which is similar to Seawall. However, Gatekeeper provides per-VM isolation. It does not distinguish the source from the destination. The aforementioned approaches fall short when average aggregate bandwidth demand exceeds a link capacity. Our VMs placement mechanism avoids over-
subscription by initial placement phases considering bandwidth demand.

**VMs placement:** Wang et al. [11] model the issue as a stochastic bin packing (SBP) problem. Breitgand et al. [3] improve the performance of Wang’s work. However, [11] does not explain how they can obtain bandwidth demand. [3] abstracts oversubscription factors as an overflow probability $p$. We doubt that whether a single value $p$ can truly represents daily traffic distribution. Secondly, the result of the aforementioned work shows that their algorithm is only efficient to minimize the number of servers. Although [3] argue that oversubscription reduction performance is still enough in present public clouds, an evidence is anecdotal. Thus, we design a mechanism that surely reduces oversubscription based on practical traffic measurement.

### 3. OUR APPROACH AND CHALLENGES

[2, 4] show that the traffic distribution in data centers follows Wei-bull and Poisson probability distribution over time. The wider the range of observations is (in terms of weeks, months, and years), the clearer the result is. Particularly, although demands of tenants increase as services grow, the peak time and the off-peak time are invariant. Therefore, our basic idea is to place VMs having opposite traffic distributions in the same server, which leads to reduce oversubscription of network resources and increase link utilization.

The motivation is illustrated in Figure 1. A service related to banking and stock trading shows the traffic distribution of Figure 1 (a) where there is heavy traffic usually in the morning and afternoon. On the other hand, the traffic of online games can have the distribution of Figure 1 (b). The two kinds of services have different times of peak demand and therefore, if VMs of the two services are placed together in the same server, we can obtain the results of Figure 1 (c). The mixed placement alleviates interference among the different kinds of services and helps the data center to have network performance isolation.

For this approach, we must solve the following questions.

- How can we get the traffic distribution and demand of each tenant?
- Given the traffic distribution, how can we allocate VMs to servers?

For the first question, existing work [3, 11] is based on statistical modeling to expect the demand for network resources. However, instead of expectation, we decide to measure the demand over a period of time because measurement is more accurate.

To solve the second question, we adopt the variation of the Stable Marriage Problem mentioned in game theory. In Stable Marriage Problem [7], given $n$ men and $n$ women, who have different preference values for the member of the opposite sex, according to their preference value. The job is to determine an assignment where each man is married to one woman. Our matching algorithm assigns VMs to proper servers. Detailed methods are described in section 4 and 5.

### 4. ARCHITECTURE

Two parts comprise the architecture of *Incubating*. *Incubator* is the place where VMs’ traffic information is measured. Traffic measurement is performed by a tenant unit to avoid traffic blending. Overseer obtains traffic distribution from *Incubator*, and performs the stable matching algorithm. For reliability, Overseer has reserves that replace his job during failure.

#### 4.1 Incubator

*Incubator* is a server cluster to measure traffic distribution of tenants. As illustrated in Figure 2, *Incubator* is not an independent server cluster, but a subset of a data center. In detail, we bind vacant servers as a cluster. Hence, it is cost-efficient because a provider does not have to establish extra servers for *Incubator*.

*Incubator* measures traffic as a tenant unit to avoid traffic blending with the other tenants. We define ‘one server, one tenant’ principle that only VMs of a single tenant can be consolidated in a server of *Incubator*. For example, in Figure 3 (a), a VM of tenant A is placed in server 1. In server 2, three VMs of tenant B are consolidated. However, in Figure 3 (b), as all VMs are placed after *Incubating*, four VMs are consolidated in server 3.

The size of *Incubator* depends on input size change. If
we set the size extremely large, some servers of Incubator become ‘no man’s land’ that means it will not be utilized either for measurement or running services. Furthermore, it causes deficiency of servers where VMs will be placed. Reversely, if the size is immoderately small, requested VMs cannot be placed into Incubator timely.

To avoid the issue, we design a skinny and input adaptive size adjustment manner as follows. Let $R$ be a set of VMs that a tenant requests. Let $n$ be the maximum number of VMs which can be consolidated in a server. $n$ is determined by system resource status. However, we assume that $n$ is the number of CPU cores in a server for simplicity. Note that our focus is network resources, not system resources. Hence, maximum four VMs can be consolidated in a server by the assumption. The initial size of Incubator starts from zero. If the number of requested VMs is 6, Incubator size increases to two by (1). Therefore, a server accommodates four VMs and the other one takes remained two VMs. Thus, Incubator checks ‘no man’s land’ and always maintains his skinny size.

$$|u| = \begin{cases} \left\lfloor \frac{|R|}{n} \right\rfloor + 1 & (|R| \mod n \neq 0) \\ \left\lfloor \frac{|R|}{n} \right\rfloor & (|R| \mod n = 0) \end{cases}$$

(1)

4.2 Overseer

Overseer is an independent server that manages Incubating as illustrated in Figure 2. It performs matching algorithm to place VMs into a data center after gathering traffic information. Overseer table stores the information, and Overseer updates his table every iteration of the matching algorithm to maintain the latest information. In Overseer table, server number indicates unique identification number of a server. Vacancy row stores the information of available system resources, and Overseer refers this row when he performs matching algorithm to place VMs. Available resources row stores remained network resources as an array. Lastly, Flag row is expressed in a boolean. The status of a server is determined by the value ‘True/False’.

To provide reliability, we design Overseer as a master-reserves architecture as illustrated in Figure 4. Master server performs Overseer’s job, and reserves are always on standby. Master delivers an alive packet per common data centers packet interval 1,000 µs [2] to reserves. After that, reserves update their time stamp. If the timestamp is not updated over 3,000 µs after the last update, a reserve checks the status of master and if the master failed, the reserve that detected master’s fail first succeeds master’s job. After that, the successor inform reserves that succession is done.

5. ALGORITHM

In this section, we present how Incubating works. Algorithm can be divided into two parts. One is measurement process of VMs’ traffic distribution and demands. The other part is performing matching algorithm to place VMs into a data center.

5.1 Traffic Measurement

As illustrated in Figure 2, when a tenant requests VMs, Overseer checks whether Incubator can accommodate requested VMs, and adjusts the size of Incubator as we described in section 4. Lastly, Overseer place VMs into Incubator based on ‘one server, one tenant’ principle.

Traffic measurement is performed for 30 days which is an enough period to obtain the average traffic distribution of VMs. Let $U$ be a set of servers that comprise Incubator. Each $b \in B$ is a traffic vector of a server $u$. Each $u \in U$ updates its accumulated traffic information $ABu$ with new information $b^t$ for every single day. Thus, traffic vector $b_t$ can
5.2 Matching Algorithm

Our algorithm for placement into data center is a variation of stable matching algorithm [7] that solves stable marriage problem. In our algorithm, the details are almost same except assumption that n proposers and m accepters exist in contrast to the original assumption that the number of proposers and accepters is same. We assume VMs, will be placed into data center, as a proposer of a man who proposes a woman. Servers in data center are assumed for a woman accepter who determines whether accepts a proposal or not. All VMs and servers have preference for each. VM prefers a server who has higher value when his demands subtract from available resources of a server. A server prefers a VM who demands less resource. This setting provides flexibility when excepted network trouble which is caused by a burst error.

Matching has two steps. Step 1 is the process of preference calculation for each other. Step 2 is to place VMs into the most appropriate server where can reduce the occurrence probability of network oversubscription. We now present these steps as follows.

Step 1: Calculation of preferences Let V = {v1, ..., vn} be a set of VMs, and S = {s1, ..., sm} be a set of servers. Each v ∈ V and s ∈ S has an ordered list of his (VMs) or her (servers) preference list. The list is a temporary list which is perished after matching. A set A = {a1, ..., am} indicates free resources of each server, and D = {d1, ..., dm} is a set of demands of each VM. Elements of set A and D are not a single value but an array since it stores resources information by discrete time unit. A ith preference of each v to s, \( P_{v_i,s_i} \) is calculated as we described in equation (3). We used maximum value of demands since it provides a simplification of problem solving. A ith preference of each s to v, \( P_{s_i,v_i} \) is simply determined by following equation (4).

\[
\Delta(a, d) = \max\{\Delta_1, \Delta_2 \} \quad (3)
\]

\[
P_{v_i,s_i} = \max(\Delta(a, d) \in D(s_i, v_i)) \quad (3)
\]

\[
P_{s_i,v_i} = \min(d \in D(v_i)) \quad (4)
\]

Step 2: Selection the most appropriate server Let \( \mu \) be a matching between a VM and a server. A pair (v, s) is a matching pair if both v and s prefer being under \( \mu \). VMs are proposer and servers are accepter. Therefore, in each iteration, an unmatched VM proposes to the first server on his preference list whom he has not proposed to yet. A server who received a proposal accepts a new proposal \( \mu(v', s) \) and rejects her current assignment \( \mu(v, s) \) if she prefers a new proposal. Matching is repeated until all VMs are matched. As a result, VMs optimal matching is performed, and VMs are migrated to servers outside Incubator. We describe the step in algorithm 1.

6. EVALUATION

We evaluate performance of Incubating comparing with the other two algorithms, Random Fit (RF) and First Fit (FF) [3] and present that our approach has succeeded to reduce oversubscriptions through traffic distribution of an arbitrary server in data center.

6.1 Simulation Setup
We compare our approach with FF, the simplest bin packing algorithm, and RF which is the naïve placement algorithm in present data center [5]. We cannot show directly compared the results between ours and [3]’s. Because they abstracts traffic as a single value overflow probability $p$. On the other hand, we consider traffic distribution with the passage of time. We generate traffic following Poisson distribution, by a minute. They also never give how we can obtain an overflow probability $p$. Lastly, their main focus is to minimize the number of servers where VMs are consolidated, not reducing oversubscription. Thus, they focus on showing minimization, not reducing oversubscription.

We set the number of servers as 10,000, and a request of tenants occurs per 20 minutes. Each request can contain maximum 20 VMs, and it follows cumulative probability distribution having 70% of requests demand below five VMs. Lastly, we categorize services into three types, ‘Day, Night, Random’ which are motivated from kinds of stock market and online games server.

6.2 Result Analysis

We select an arbitrary server which runs same services in a data center to present the result. Figure 6 shows the simulation result for each algorithm. We observe that traffic demands of both FF and RF exceeded over 100Mbps, a link capacity. FF causes relatively short and intensive oversubscription, and RF records long and moderate oversubscription. Especially, as FF records oversubscription exceeded over 120Mbps, the services undergo performance interference.

Our approach shows an extremely smooth traffic distribution since VMs having contrasted distribution are consolidated as we intend in Figure 1. Each server may have dissimilar distribution, however, in general, a server which VMs are placed by Incubating shows that the highest demand is always under 100 Mbps. Thus, we present that our approach is efficient to reduce oversubscription by detail example of an arbitrary server in data center.

We now demonstrate whether our approach is valid in all servers used for simulation. Figure 7 is the comparison result of each algorithm’s demands proportion of the moment when traffic demand is the highest in a day among servers. 20% and 35% of servers show oversubscriptions for RF and FF, respectively. Adversely, the case does not occur in Incubating. Thus, we can know that our proposal is valid in all servers in data center. Lastly, in Figure 6 and 7, most demands for Incubating has a range that larger than 50Mbps and less than 100Mbps. From the result, we can obtain one more significant observation that ours not only reduces oversubscription but also increases link utilization.

7. CONCLUSION AND FUTURE WORK

In this paper, we address network isolation issue in cloud data centers. We proposed a traffic-aware VMs placement mechanism, not only reduces oversubscriptions but also increases link utilization. Our approach obtain initial traffic
demand in a server cluster, and place VMs by the stable matching algorithm. For the future work, we will focus on joint VMs placement considering both system and network resources.

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9. REFERENCES