From VM Consolidation to Data Center Consolidation

Xuanjia Qiu

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Outline

- Consolidation of virtual machines
- Consolidation of data centers

VM Consolidation

- Find out optimal placement of virtual machines onto physical servers in a data center
  - Power consumption is not proportional to the workload on a physical server
  - In order to save energy: allow to shut down more e physical servers or put them into low power consumption state

- Types of VM consolidation
  - Static consolidation
  - Semi-static consolidation
  - Dynamic consolidation
- Typically modeled as
  - Bin Packing problem (BP)
  - Stochastic Bin Packing problem(SBP)
- Consolidation schemes focus on CPU, memory, disk I/O, and/or network bandwidth

Bin Packing problem

Given a set of numbers $S = \{X_1, ..., X_n\}$ where $X_i \in (0, 1)$. Partition S into sets $S_1, ...S_m$ (each set is called a bin. The sum of numbers in each bin does not exceed 1. Find a partition in which the numbers of bins is minimum.

- NP hard
- First Fit Decreasing (FFD)(proved a worst case performance ratio 11/9, tight)
- Only suitable for static consolidation

VM condensation with awareness of network bandwidth over-subscription

- Since VMs do not simultaneously use maximum of their nominal bandwidth, the capacity of the physical containers can be multiplexed
  - The standard deviation of the random variables that represents the total bandwidth demand is smaller than the sum of standard deviations of the individual variables (smoothing)

Stochastic Bin Packing

- Consolidation under the constraint of bandwidth subscription

Given: a set of items $S = \{X_1, ..., X_n\}$ where each item is a random variable. X_i are independent, and follow normal distribution $N(\mu_i, \sigma_i)$.

A packing of S to the bins is a partition of S into sets $S_1, ...S_m$. A packing is feasible if for every bin j, $Pr[\sum_{i:X_i \in S_j} X_i > 1] \leq p$, where p is a given *overflow probability* (QoS constraint).

SBP is to find a feasible packing that consumes minimum number of bins.

- In IEEE INFOCOM 2011, Wang et al. [3] proposed an online algorithm with competitive ratio of $(1+\epsilon)(1+\sqrt{2})$
- In IEEE INFOCOM 2012, Breitgand et al. [6] proposed an online algorithm with competitive ratio $(2+\epsilon)$

Online SBP algorithm

Lemma 3.1: A packing is feasible for a given overflow probability p if and only if for every bin j, $\sum_{i:X_i \in S_j} \mu_i + \beta\sqrt{\sum_{i:X_i \in S_j} \sigma_i^2} \leq 1$, where $\beta = \Phi^{-1}(1-p)$ and the quantile function Φ^{-1} is the inverse function of the CDF Φ of $\mathcal{N}(0,1)$.

Denote the variance to mean ratio (VMR) of item i by $d_i = \frac{\sigma_i^2}{\mu_i}$.

- Framework of Algorithm:
  - Classify next item according to the VMR classes
  - Place the next item in the first bin of its class into which it can be feasibly packed according to Lemma 3.1. If no such bin exists, open a new bin in this class to pack this item.

Data Center Consolidation

- Perform a consolidation of applications across data centers and transform the IT infrastructure of an enterprise with multiple data centers into fewer data centers
- VM consolidation emerges in around 2007, which is relatively mature now. Interest on data center consolidation arises since the year of 2010, when a report on U.S. government data center condensation is published.
- Analogy:
  - Application group vs. VM
  - Data center vs. Physical Server

Model as a Linear Programming

$$\text{Minimize: } \sum_{j=1}^{j=N} \sum_{i=1}^{i=M} X_{ij} \left(S_i(Q_j + \alpha E_j + \frac{T_j}{\beta}) + D_i W_j + L_{ij} \right)$$

$$\text{Subject To: } 1) \sum_{j=1}^{j=N} X_{ij} = 1, \forall 1 \leq i \leq M,$$

$$2) \sum_{i=1}^{i=M} X_{ij} S_i \leq O_j, \forall 1 \leq i \leq N, \quad 3) X_{ij} \in \{0, 1\}$$

- Objective function:
  - Cost at data centers for space, power, labor, WAN communication and latency penalty
- Constraints:
  - (2): not exceed capacity of any data center
  - (1)(3): every application group is assigned with a data center

Add-on of VPN

Minimize: $\sum_{j=1}^{j=N} \sum_{i=1}^{i=M} X_{ij} \left(S_i (Q_j + \alpha E_j + \frac{T_j}{\beta}) + D_i W_j + L_{ij} \right)$
Subject To: 1) $\sum_{j=1}^{j=N} X_{ij} = 1, \forall 1 \leq i \leq M,$
2) $\sum_{i=1}^{i=M} X_{ij} S_i \leq O_j, \forall 1 \leq i \leq N,$ 3) $X_{ij} \in \{0, 1\}$

- Replace $D_i W_j$ by

$$\sum_{r=1}^{r=R} \left((C_{ir} D_i) / (\gamma * \sum_{r=1}^{r=R} C_{ir}) \right) (F_{jr})$$

- Leased VPN is charged based on communication distance and number of links

My comment

- The research on data center consolidation is in the preliminary state.
- Exploration directions:
  - Model overload of application groups as random variables
  - Various types of cost vary along time
  - Consider the interaction between application groups
  - Is dynamic consolidation of data center possible?

Reference

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