Multi Criteria Decision Making for Resource Management in Virtualized Environment

Zar Lwin Phyo
University of Computer Studies, Mandalay
zarlwinphyo@gmail.com

Abstract

The workload in each node changes dynamically over time in large-scale data centers, so the workload in some machines may exceeds the threshold, which not only can't guarantee the quality of service requirements (QOS), may also waste resources. One of the key benefits of virtualization is reassignment of a virtual machine to another physical host can be done when resource shortage or poor utilization conditions occurs in host. In this paper, we proposed the decision support system for resource management in Virtualized Data Center (VDC) based on the integrated approach of Analytical Hierarchy Process (AHP) and the Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE). In this case, AHP is used to assign weights to the criteria to be used in selection phase, while PROMETHEE is employed to determine the priorities of the alternatives.

1. Introduction

Data center are inexorable growing in a variety of domains such as enterprise systems, e-commerce sites and web hosting. Server resources in a data center are multiplexed across multiple applications--each server runs one or more applications. Further, each application sees dynamic workload fluctuations caused by incremental growth, time-of-day effects, and flash crowds [5].

These applications are usually business critical applications with Quality-of-Service (QoS) requirements. To guarantee that an application will always be able to cope with all demand levels the application is statically allocated enough resources so that peak demand is satisfied. The unit of allocation is typically a physical machine. This often results in resources being underutilized [3]. An Applicable approach for reducing management complexity is to employ virtualization. In this approach, applications run on virtual servers that are constructed using virtual machines, and one or more virtual servers are mapped onto each physical server in the system. Virtualization of data center resources provides numerous benefits. It enables application isolation since malicious or greedy applications can't impact other applications collocated on the same physical server. It enables server consolidation and provides better multiplexing of data center resources across applications. Perhaps the biggest advantage of employing virtualization is the ability to flexibly remap physical resources to virtual servers in order to handle workload dynamics. Migration is transparent to the applications and all modern virtual machines support this capability [1, 7].

Each virtual machine sees workload fluctuation from time to time and resources requirement changes. An increase in workload can be handled by allocating more resources to it, if idle resources are available on the physical server. If Physical Machine (PM) does not have enough or no idle resources to satisfy Virtual Machine's requirement, the initial placement may lead to Service Level Agreement (SLA) violation and performance degradation.

In order to avoid SLA violation and performance degradation, live migration, the biggest advantage of virtualization, is used to handle. When virtual machines (VMs) are needed to be migrated from one server to another, the migration controller needs to decide which VMs should be migrated away and also decides where to migrate in datacenter[4]. When average utilization of a host reaches below defined threshold, underload condition, migration can also be made. In this case, all VMs from underloaded server are moved to other appropriate servers and then it is shut down in order to save energy cost. They can also be moved back into an active state and re-introduced into the running state when load peaks.

This paper presents a two-level resource management system that enables adaptive resource allocation in accordance with Service Level Agreements (SLA).The main objective of this study is to propose an evaluation model for the selection of an optimal alternative among a set of available alternatives. This problem is Multi Criteria Decision Making (MCDM) problem where many criteria should be considered in decision-making. Therefore, this study utilizes a MCDM method (AHP) to determine the importance weights of evaluation criteria, and PROMETHEE to obtain the performance ratings of the feasible alternatives in linguistic values parameterized.

2. Related Work

Zhikui Wang et.al. presented AppRAISE, a distributed management system for application performance control and dynamic resource allocation in virtualized server environments. They extended a traditional queuing model to represent application performance. They considered only CPU resource and only calculated the mean response time, which can be misleading [13].

In the work of T.Wood et.al., Sandpiper [10], a hotspot detection algorithm that determines when to migrate virtual machines, and a hotspot mitigation algorithm that determines what and where to migrate was proposed. They defined a new metric that captures the combined CPU-network-memory load of a virtual and physical server. M.tarighi et.al.[8] presented a new method to migrate VMs between cluster nodes using TOPSIS algorithm. After completing the ordering of physical servers and VMs, migration decisions are made to move most overloaded VMs from the most overloaded physical machine to the least overloaded machine.

Y.O.Yazir et.al. [12], introduced a new approach for dynamic autonomous resource management in computing cloud. PROMETHEE II method was used for resource configuration. But they assumed all criteria have equal weigh in decision making. But considering the status of each parameter makes such an assumption unrealistic. For example, when the virtual machines are Web server, the probability of CPU saturation is more than RAM saturation. Because of the Web server are CPU-intensive load. Therefore, the weight of CPU and RAM influence are not equal. In this case, we use AHP method to calculate the weight of each criterion.

3. Autonomic Resource Management

This section provides an overview of resource management system for virtualized environment. We assume that the target virtualized environment offers multiple transactional Web services, and each service represents a different Internet application. A set of heterogeneous servers are included in this system, each of which runs a Virtual Machine Monitor, such as VMWare or Xen. Physical resources of each server such as CPU, disks, memory, network are allocated among multiple virtual machines. Virtualization enables the flexible reduction and expansion of the resource capacity assigned to each VM. Our system is based on a hierarchical structure such as Virtual Machine Controller (VMC) and Virtual Resource Manager (VRM). We made a few assumptions driven by the goal of meeting a reasonable trade-off between accuracy and practical solution time. We assume request-based work load model in which load requests arrive according to a Poisson process, as observed in several real systems and assumed by most previous solutions. Moreover, we assume that each virtual machine runs a single independent task.

3.1. Virtual Machine Controller (VMC)

VMC is associated with each physical machine. Our VMC combines a prediction model and allocation model. Although there are server's many resources, we consider CPU as representative for the resource allocation problem. Prediction model monitors VM resource usages in the resource pool at every five minutes interval and estimates the resource usage for the next time interval. The allocation model uses these estimates to determine the fraction of capacity to be assigned to each VM. Our approach to the design of such controller is based on linear regression method. However, in this paper, we emphasize the operation of Virtual Resource Manager.

3.2. Virtual Resource Manger (VRM)

There may occur an unbalanced condition in data center when one host is overloading and another one is underloading. This situation can be handled by Virtual Resource Manager (VRM). VRM is centralized and is hosted on a dedicated server. VRM performs different operation upon underload condition and overload condition. In overload condition, VRM tries to move the most overloaded VM to other destination host. In this case, VRM ranks VMs of overload server by their score of descending order. The highest score of VM is most appropriate one to be migrated. And then, VRM finds the most preferable destination host for that VM. In this case, the PMs are also ranked in descending order. The machine with highest score is defined as the most overloaded server and the one with lowest score is the most appropriate destination host for VM to be migrated. In the case of underload condition, VRM ranks the hosts to know which one is the least loaded host and target host. Then VRM move all of the VMs on the least loaded machine to that appropriate target machines and then it is shutdown to save energy costs. In order to deal with this problem, we use the combination of AHP and PROMETHEE methods. In our case some of the criteria will be maximized while some of them will be minimized based on the criteria.

3.3. Analytical Hierarchy Process (AHP)

AHP was developed by Saaty at 1980 [9]. It addresses how to determine the relative importance of a set of activities in a multi-criteria decision problem. The AHP method is based on three principles: first, structure of the model; second, comparative judgment of the alternatives and the criteria; third, synthesis of the priorities.

In the literature [2], AHP has been widely used in solving many complicated decision-making problems.

3.4. PROMETHEE

The PROMETHEE (Preference Ranking Organization METhod for Enrichment Evaluation) method was developed by Brans and Vincke in 1985 [6]. The PROMETHEE I method can provide the partial ordering of the decision alternatives, whereas, PROMETHEE II method can derive the full ranking of the alternatives. Therefore the PROMETHEE II method is employed to obtain the full ranking of the alternative criteria for VM migration decision. The procedural steps as involved in PROMETHEE II method are enlisted as below:

Step 1: Calculate the preference function, $P_j(i,i')$.

There are mainly six types of generalized preference functions as proposed by Brans and Mareschal [6]. But these preference functions require the definition of some preferential parameters, such as the preference and indifference thresholds. However, in real time applications, it may be difficult for the decision maker to specify which specific form of preference function is suitable for each criterion and also to determine the parameters involved. To avoid this problem, a simplified preference function is adopted by V.M. Athawale and S. Chakraborty [11]. Therefore we used this preference function in this paper.

$$P_j(i,i') = 0 \quad \text{if } R_{ij} \leq R_{i'j} \qquad (1)$$

$$P_j(i,i') = (R_{ij} - R_{i'j}) \quad \text{if } R_{ij} > R_{i'j} \qquad (2)$$

Step 2: Calculate the aggregated preference function taking into account the criteria weights.

Aggregated preference function,

$$\pi(i,i') = \left[\sum_{j=1}^{m} w_j * P_j(i,i') \right] / \sum_{j=1}^{m} w_j \qquad (3)$$

where wj is the relative importance (weight) of j^{th}criterion.

Step 3: Determine the leaving and entering outranking flows as follows:

Leaving (or positive) flow for i^{th} alternative,

$$\varphi^{+}(i) = \frac{1}{n-1} \sum_{i=1}^{n} \pi(i,i') \qquad (i \neq i') \qquad (4)$$

Entering (or negative) flow for i^{th} alternative,

$$\varphi^{-}(i) = \frac{1}{n-1} \sum_{i=1}^{n} \pi(i',i) \qquad (i \neq i') \qquad (5)$$

where n is the number of alternatives.

Here, each alternative faces (n – 1) number of other alternatives. The leaving flow expresses how much an alternative dominates the other alternatives, while the entering flow denotes how much an alternative is dominated by the other alternatives. Based on these outranking flows, the PROMETHEE I method can provide a partial preorder of the alternatives, whereas, the PROMETHEE II method can give the complete preorder by using a net flow, though it loses much information of preference relations.

Step 4: Calculate the net outranking flow for each alternative.

$$\varphi(i) = \varphi^{+}(i) - \varphi^{-}(i) \qquad (6)$$

Step 5: Determine the ranking of all the considered alternatives depending on the values of $\varphi(i)$. The higher value of $\varphi(i)$, the better is the alternative. Thus, the best alternative is the one having the highest $\varphi(i)$ value.

4. Numerical Evaluation

To make a numerical evaluation, we used the state information of resource pool of a VDC that is presented in [8]. As Table 1 indicates it has 5 PMs and 12 VMs.

Table 1. Physical Machines and its virtual machines

Physical Machine	Virtual Machine
PM_1	VM_5, VM_6
PM_2	VM_7
PM_3	VM_1, VM_2, VM_3, VM_4
PM_4	VM_8, VM_9, VM_{10},
PM_5	VM_{11}, VM_{12}

Table 2. State information of PMs

PM	CPU %	RAM %	NET %	CPU Clock Speed	RAM Capacity	Network BW
PM1	15	32	13	2	2	100
PM2	0	2	0	1.2	1	1000
PM3	81	60	40	1.8	2	100
PM4	70	49	85	3.2	1	1000
PM5	53	70	16	2.4	6	100

Table 2 shows the state information of Physical Machine. In this table, the CPU usage of each node in percent (CPU%), RAM usage of each node in percent (RAM %), Network usage in percent (NET%), RAM Capacity of each node, Network Bandwidth (Network BW) and CPU Clock Speed in GHz of each node are presented. According to this table, physical machine 3 has obtained the highest score. It means that this node is in danger and migration is inevitable. Therefore, virtual machines of PM3 are needed to know which one should be migrated away.

4.1. VM Selection

CPU usage percentage is the most preferable criteria for the data center's administrator because of the most of the servers are running CPU intensive application in this resource pool.

4.1.1 Calculate the weight of criteria for VM selection

In this phase, the weights of the criteria to be used in evaluation process are calculated by using AHP method. In this phase, the experts in the decision making team are given the task of forming individual pairwise comparison matrix by using the scale given in Table 3. For virtual machine migration, four criteria (C) were considered and their state information is shown in Table 4. In this case, C_1, C_2 andC_3 are defined as benefit criteria. C_4 is defined by cost criteria because virtual machine which has the lowest RAM usage is the optimal virtual machine that should be migrated. The more memory pages are used by the VM, the more migration time it will take. The pairwise comparison matrix that represents the relative importance of one criterion over another that is defined by decision maker is presented in Table 5.

Table 3. Nine-Point intensity of importance scale and its description

Definition	Intensity of Importance
Equally Importance	1
Moderately more Importance	3
Strongly more Importance	5
Very Strongly more Importance	7
Extremely more Importance	9
Intermediate values	2 , 4 , 6 , 8

Table 4. State information of VMs

	CPU%	RAM%	NET%	RAM Usage
VM_1	15	23	13	0.6
VM_2	0	0	0	0
VM_3	60	67	58	0.4
VM_4	54	56	72	1

Table 5. Pairwise comparison matrix

	C_1	C_2	C_3	C_4
C_1	1	3	5	2
C_2	0.33	1	2	0.5
C_3	0.2	0.5	1	0.5
C_4	0.5	2	2	1

Table 6. Weight value of each criteria

Criteria	Weight Values
C_1	0.489
C_2	0.162
C_3	0.098
C_4	0.251

λ_{max} = 4.015, CI = 0.005 ,RI = 0.9 , CR = 0.005 < 0.1 (acceptable)

According to Table 6, CPU% and RAM usage are determined as the two most important criteria in VM selection process by AHP. Consistency ratio of the pairwise comparison matrix is calculated as 0.005 < 0.1. So the weights are shown to be consistent and they are used in the selection process.

4.1.2. Evaluation of alternatives and determine the final rank for VM

Leaving flow and entering flow of each alternative is calculated by using Eq. (4) and Eq. (5). Then net outranking values of alternatives VM is established by using Eq. (6). This is shown in Table 7. According to the descending order of this net outranking flow, VM_3 should be migrated away.

Table 7. Net outranking values for VMs

	Leaving Flow	Entering Flow	Net Flow	Rank
VM_1	0.075	0.309	-0.234	3
VM_2	0.125	0.411	-0.286	4
VM_3	0.393	0.029	0.364	1
VM_4	0.299	0.145	0.154	2

Table 8. Weighted and unweighted rankings

	Weighted Net Flow	Weighted Ranking	Unweighted Net Flow	Unweighted Ranking
VM_1	-0.234	3	-0.41	3
VM_2	-0.286	4	-0.80	4
VM_3	**0.364**	**1**	**0.30**	**2**
VM_4	**0.154**	**2**	**0.58**	**1**

The case in which criteria weights are not considered, i.e., the criteria have equal priorities, is analyzed and the net flow values obtained in this conditions are presented in Table 8 with their comparisons with previous values.

4.2. Target Server Selection

The same steps of calculation are taken in target server selection. In this case of target server selection, six criteria are used as shown in Table 2. The first three criteria are defined as benefit criteria and the last three criteria are used as cost criteria because the physical machine with the higher value of them is capable for higher load.

4.2.1. Calculate the weight of criteria for Target Server selection

The relative importance of one criterion over another that is defined by decision maker and priority value of each criterion are shown in Table 9 and Table 10.

Table 9. Pairwise comparison matrix

	C_1	C_2	C_3	C_4	C_5	C_6
C_1	1	3	5	1	3	5
C_2	0.33	1	2	0.33	1	2
C_3	0.2	0.5	1	0.2	0.5	1
C_4	1	3	5	1	3	5
C_5	0.33	1	2	0.33	1	2
C_6	0.2	0.5	1	0.2	0.5	1

Table 10. Weight value of each criteria

Criteria	Weight Values
C_1	0.289
C_2	0.120
C_3	0.064
C_4	0.341
C_5	0.120
C_6	0.064

λ_{max} = 6.135, CI = 0.027 ,RI = 1.24 , CR = 0.021 < 0.1 (acceptable)

CPU % and CPU Clock Speed are also determined as the two most important criteria in the PM selection process by AHP. Consistency ratio is calculated as 0.021 < 0.1. So the weights are shown to be consistent and they are used in the selection process.

4.2.2. Evaluation of alternatives and determine the final rank for target server

Table 11. Weighted and unweighted values for PMs

	Weighted Net Flow	Weighted Ranking	Unweighted Net Flow	Unweighted Ranking
PM_1	**0.381**	**3**	**-.099**	**5**
PM_2	**-0.052**	**5**	**0.79**	**2**
PM_3	**0.731**	**1**	**-0.98**	**4**
PM_4	**0.383**	**2**	**0.99**	**1**
PM_5	**0.0.89**	**4**	**0.01**	**3**

Table 11 shows the weighted and unweighted values for PMs. According to this table Physical host 3 is the most overloaded server and Physical 2 is the least loaded server. Therefore, Physical host 2 is chosen as the destination server.

Table 12 shows the ranked obtained with different ranking methods.

Table 12. Ranked obtained by different ranking methods

Actual Rank	PROMETHEE	AHP and PROMETHEE
PM_3	PM_4	PM_3
PM_4	PM_2	PM_4
PM_5	PM_5	PM_1
PM_1	PM_3	PM_5
PM_2	PM_1	PM_2

4.3. Time Complexity

In our method, score of PM and VM are needed both of which can be calculated by the same way. Therefore, it is easy to get the complexity for score calculating is *O(n)* times more than PROMETHEE. However, we can easily find that calculation of the criteria weights is important and they could change the ranking.

5. Conclusion and Future Work

In the case of resource shortage or poor utilization of host, reassignment of a virtual machine to another physical host is required in virtualized data center. This decision involves many parameters that are interrelated in that changes in some parameters affect the others. In this paper, we proposed the decision support system for VDC. In this case, AHP is used to assign weights to the criteria to be used in selection phase, while PROMETHEE is employed to determine the priorities of the alternatives. The weights obtained from AHP are included in decision making process by using them in PROMETHEE computations and the alternative priorities are determined based on these weights. Additionally, it is shown that calculation of the criteria weights is important in PROMETHEE method and they could change the ranking.

In the future, we would like to complete the operation of VMC and VRM and also intend to develop effective resource management system for the virtualized data center. Moreover, some criteria could have a qualitative structure or have an uncertain structure which cannot be measured precisely. In such cases, fuzzy numbers can be used to obtain the evaluation matrix. This will improve the proposed method and is one of the directions in our future research.

References

[1] C.Clark, K.Fraser, S.Hand, J.Hansen, E.Jul, C;Limpach, I.Pratt, A.Warfiel, " Live Migration of Virtual Machines" Proceedings of Usenix Symposium on Network Systems Design and Implementation (NSDI), May 2005.

[2] F.T.S.Chan.et.al., "Global Supplier Selection: a fuzzy-AHP approach", international Journal of Production Research. DOI:10.1080/ 00207540600787200.

[3] G. Keller and H. Lutfiyya, " Replication and Migation as Resource Management Mechanisms for Virtualized Environments", Sixth International Conference on Autonomic and Autonomous Systems, 2010.

[4] J.Almeida et.al., "Joint Admission Control and Resource allocation in Virtualized Servers",

[5] K.Appleby, S.Fakhouri, L.Fong, M.Goldszmidt, S.Krishnakumar, D.Pazel, J.Pershing, B.Rochwerger, "Oceano-sla-based management of a computing utility", Proceedings of the IFIP/IEEE Symposium on Integrated Network Management, May 2001.

[6] M.Doumpos and C.Zopoundidis, "A multi-criteria classification approach based on pair-wise comparison", European Journal of Operation Research,158,378-389, 2004.

[7] M.Nelson, B.H.Lim, G.Hutchins, "Fast transparent migration for virtual machines", USENIX Annul Technical Conference, 2005.

[8] M.Tarighi et.al. " A New Model for Virtual Machine Migration in Virtualized Cluster Server Based on Fuzzy Decision Making", Journal of Telecommunications,volume 1, issue 1,February 2010.

[9] T.L.Saaty, "The Analytic Hierarchy Process", McGraw-hill,New York, 1980.

[10] T.Wood et.al. "Sandpiper: Black-box and Gray-box Resource Management for Virtual machines", Comput.Netw.doi:10.1016,Elsevier,2009.

[11] V.M.Athawale et.al., "Facility Location Selection using PROMETHEE II Method", Proceedings of the International Conference on Industrial Engineering and Operations Management Dhaka,Bangladesh,2010.

[12] Y.O.Yazir et.al., "Dynmic Resource allocation in Computing Clouds using "Distributed Multiple Criteria Decision Analysis ", IEEE 3rd International Conference on Cloud Computing, 2010.

[13] Z.Wang.et.al, "AppRAISE: Application-Level Performance Management in Virtualized Server Enviruonments", IEEE Transactions on Network and Service Management, vol.6,No.4,December,2009.