Resource Management in Virtualized Data Center Based-on AHP and TOPSIS under Fuzzy Environment

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Abstract

In this paper, a three level resource management system for virtualized data center is presented. Three levels are defined as vitrual machine level controller (VLC), host level controller (HLC) and central level controller (CLC). When ideal resources are available, VLC and HLC can perform resource management. In the case of overloading or underloading condition at a host, CLC manages resources by giving migration decisions. This paper presents an evaluation model for the decision support of VM migration in VDC based on the analytical hierarchy process (AHP) and the technique for order preference by similarity to ideal solution (TOPSIS) under fuzzy environment. VM and target server selections are multi-criteria decision making problems. AHP is used for criteria weight consistency checking and Fuzzy TOPSIS is used for final ranking. The numerical evaluation is conducted to illustrate the utilization of the model.

1. Introduction

Because of the advantage of server consolidation, a variety of virtual machines are co-located on the same physical server and they serve a variety of services including web services, file services etc. Some of the services of virtualized data center (VDC) are CPU – intensive while others are RAM - intensive and so on [3]. Because of the dynamic features of workload increases in VDC, remapping virtual resources to physical resources is required. Such workload increase can be handled by increasing the resources allocated to a virtual server, if idle resources are available on the physical server. But when it has not ideal resources, overloading condition of any resource dimension can occur at the physical host.

Such condition can be handled by one of the biggest advantage of the ability of migrating virtual machines. In this case, the migration controller needs to choose the proper VM to be migrated and destination server at a time. For a proper selection, the decision maker may need a large amount of data to be analyzed and many factors to be considered.

Because of the requirements of multi-level and multi-factor features, so such difficulties can be regarded as multiple criteria decision-making (MCDM). The more criteria are considered, the more computational overhead it can take. But the insufficient number of criteria can cause inefficient decisions. Therefore, the decision maker is needed to balance the trade-off between number of criteria and the computational overhead.

In this system, data center level management, namely, CLC takes the responsibility for decision support of virtual machine migration. Four criteria are used for VM selection and six criteria are used for target server selection. Several methods exist for MCDM problems. Among them, AHP and fuzzy TOPSIS are chosen in this paper. AHP is used to check the consistency of the weights of the criteria and TOPSIS is used for alternative ranking. Instead of original TOPSIS, fuzzy-TOPSIS is chosen in this model as it can deal with decision maker ambiguities, uncertainties and vagueness, which cannot be handled by crisp values. From the numerical evaluation, we can see that the combination of AHP and fuzzy-TOPSIS can help the data center administrator for decisions of virtual machine migrations when they are selecting the proper virtual machine and target server.

The rest of the paper is structured as follows. Section 2 presents the related work of this paper. Section 3 is about the three level resource management controllers in virtualized data center. Section 4 will explain about the background theory of central level management in virtualized data center. It will be followed by numeric calculation in section 5. Section 6 concludes the paper. References are shown in Section 7.

2. Related Work

This section presents the related work that is considered for resource management of virtualized data center and virtual machine migrations. Sandpiper [10] automates the task of monitoring and detecting hotspots, determining a new mapping of physical to virtual resources and initiating the necessary migrations. But Sandpiper did not take into account the complicated and uncertain relationship between the system's parameters. P.Paddala [9] presents their system as automated control of multiple virtualized resources. Auto control is a resource control system that automatically adapts to dynamic workload changes to achieve application service level objectives (SLO). The model estimator captures the complex relationship between application performance and resource allocations, while the MIMO controller allocates the right amount of multiple virtualized resources to achieve application SLOs. In online model estimator, they used adaptive modeling approach to capture the complex behavior of enterprise applications.

Jing Xu [4] proposed a two level resource management system to dynamically allocate resources to individual virtual containers. It uses local controllers at the virtual container level and a global controller at the resource pool level. They used fuzzy logic and migration decision is not considered. In [11], VMware's Distributed Resource Scheduler solves the CPU and memory pressure by performing load balancing dynamically. But VMware's DRS cannot utilize application logs to have better placement decisions. Moreover, DRS is only efficient for homogeneous virtualized environment.

In [3], M.Tarighi presents a method to migrate VMs between cluster nodes using TOPSIS algorithm to find the most loaded server. In their system, they combine the TOPSIS algorithm and fuzzy theory. In their first level of implementation, they order the physical servers and decide which the most overloaded ones are. Then the second level of operation starts by ordering the virtual machines. After completing the ordering of two steps, then migration decisions are made to move the most overloaded virtual machines from the most overloaded physical machines to the least overloaded machine. But they did not consider the consistency checking of the weights of the criteria.

3. Proposed Three-Level Resource Management Controllers in VDC

This section describes the resource management system we envision and its corresponding services. The proposed system relies on a combination of sub-processes that implement for three types of controllers in a virtualized data center. Figure 1 shows the proposed three-level resource management controllers that we visualize for a virtualized data center.

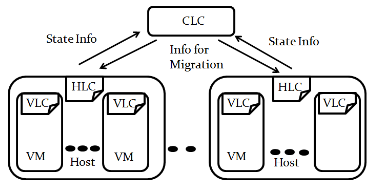

Figure 1. Architecture of three-level controllers in VDC

Three-level controllers are considered in this system such as VLC, HLC and CLC. But in this paper, we emphasize on the operation of CLC for the decision support of virtual machine migrations. We assumed that HLC inform CLC to carry out necessary migration.

3.1. Virtual Machine Level Controller

VLC sits on each of the virtual machines (VMs) for their purpose of detecting VM resource usage at every time interval and forecasting the required resource for the next time interval. If the VM has not enough resource for the next time interval, it demands for the additional requirement from HLC.

3.2. Host Level Controller

Every physical machine in the data center has their HLC to detect overload condition of the host and to solve the demands of the VLCs. HLC perform its operation by managing its physical resource if they have ideal resources when VLCs are demanding. But at the condition of VLCs request more than the existing ideal resources, HLC try to migrate some of its virtual machines. At the same time, HLC continuously monitors the host's resource utilization and identifies appropriate actions to remedy the situation whenever resource utilization values are too high or too low.

3.3. Central Level Controller

CLC performs as the central management unit of the whole data center. Whenever a host sends request message to migrate one or more of virtual machines because of overloading condition, CLC determines which VM on that server should be migrated and it searches a new server to receive the workload.

In an overload situation, CLC determines which VM should be migrated away and then it chooses an appropriate target server. The target server is the least loaded server that has sufficient resources to host the VM. If such a server does not exist, CLC suggests that a new server should be started up.

The operation of CLC on an under load condition is a quite different from the way that is defined for the overload condition. In this case, all of the VMs from the underloaded server are tried to move away. Appropriate target servers are needed to be found for each of the VM of underloaded host. If a target server cannot be found unfortunately then the shutdown process is stopped.

To solve the above mentioned cases, CLC makes its operation via two phases. When a host reports that it is overloaded, CLC tries to find the VM to be migrated. In this phase, CLC ranks the VMs of the overloaded machines according to their scores in descending order. The VM which has the highest score is the most preferable one to migrate away. The next phase is to find the appropriate target server. In this phase, the physical machines are ranked in descending order. The one with the highest score is defined as the most overloaded server and the lowest ranked machine is the proper destined server for the migrated VM. In the first phase of under load condition, CLC ranks the hosts to know which one is the least loaded server. And CLC finds the target server for all of the VMs on the least loaded machine in its second phase and then tries to shut it down. All of these approaches are done by using the combination of AHP and fuzzy-TOPSIS methods.

4. AHP and Fuzzy-TOPSIS for CLC

4.1 AHP

AHP is a process for developing a numerical score to rank each decision alternative based on how well each alternative meets the decision maker's criteria. With the AHP, the objectives, criteria and alternatives are arranged in a hierarchical structure similar to a family tree. A hierarchy has at least three levels: overall goal of the problem at the top, multiple criteria that define alternatives in the middle, and decision alternatives at the bottom. [6].

4.2 Fuzzy-TOPSIS

The TOPSIS method is a technique for order preference by similarity to ideal solution [1]. The best alternative is the one that is closest to the ideal solution and farthest from the negative ideal solution. Suppose a MCDM problem with m alternatives, A1... Am, and n decision criteria/attributes, C1... Cn. Each alternative is evaluated with respect to m criteria/attributes. All the values/ratings assigned to the alternatives with respect to each criterion form a decision matrix denoted by X = $(xij)_{nm}$. W = (w1... wn) be the relative weight vector for the criteria [5]. General TOPSIS process with six activities is listed below [2].

Activity 1

Establish a decision matrix for the ranking. The structure of the matrix can be expressed as follows:

$$D = \begin{bmatrix} f_{11} & \cdots & f_{1n} \\ \vdots & \ddots & \vdots \\ f_{m1} & \cdots & f_{mn} \end{bmatrix} \quad (1)$$

Activity 2

Calculate the normalized decision matrix $R(=[r_{ij}])$. The normalized value r_{ij} is calculated as:

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{n} f_{ij}^2}} \quad (2)$$

where j = 1…n; i = 1…m.

Activity 3

Calculate the weighted normalized decision matrix by multiplying the normalized decision matrix by its associated weights. The weighted normalized value V is calculated as:

$$v_{ij} = w_{ij} r_{ij} \quad (3)$$

where w_j represents the weight of the j^{th} attribute or criterion.

Activity 4

Determine the PIS and NIS, respectively:

$$V^+ = \{v_1^+, \ldots, v_n^+\} = \{(Max\ v_{ij} \mid j \in J), (Min\ v_{ij} \mid j \in J')\} \quad (4)$$

where J is associated with the positive criteria and J' is associated with the Negative criteria.

Activity 5

Calculate the separation measures, using the m dimensional Euclidean distance. The separation measure D_i^+ of each alternative from the PIS is given as:

$$D_i^+ = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^+)^2}, \text{ i=1,….m} \quad (5)$$

Similarly, the separation measure D_i^- of each alternative from the NIS is as follows:

$$D_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2}, i = 1, \ldots m \quad (6)$$

Activity 6

Calculate the relative closeness to the idea solution and rank the alternatives in descending order. The relative closeness of the alternative A_i with respect to PIS V^+ can be expressed as:

$$\bar{C}_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (7)$$

where the index value of $\bar{C}_i$ lies between 0 and 1. The larger the index value, the better the performance of the alternatives.

The use of fuzzy set theory allows the decision-makers to incorporate unquantifiable information, incomplete information, non-obtainable information and partially ignorant facts into decision model. As a result, fuzzy TOPSIS and its extensions are developed to solve ranking and justification problems [6].

5. Numerical Evaluation of CLC

To make a numerical evaluation, we used the state information of the resource pool of a virtualized data center that is presented in [7]. This resource pool has five physical hosts and each of them has some virtual machines. As Table 1 indicates it has total 12 virtual machines. According to the state information as shown in Table 2, we can see that physical machine 3 is the most overloaded server. In this case, CLC need to perform necessary migration when HLC reports about overloading condition.

Table 1. Physical machines and associated virtual machines

Physical Machine	Virtual Machine
PM1	VM1, VM2
PM2	VM3
PM3	VM4, VM5, VM6, VM7
PM4	VM8, VM9, VM10
PM5	VM11, VM12

Figure 2 shows the steps of main steps of CLC. In the first stage, alternative VMs of the overloaded server and the criteria are determined and the decision hierarchy is formed. AHP model is structured such that the objective is in the first level, criteria are in the second level and alternative virtual machines are on the third level. Four criteria are determined according to the data center's administrator experience and they are shown in Table 3.

Table 2. Physical machines and their state information

Physical Machine	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 3. Virtual machines and their state information

Virtual Machine	CPU%	RAM%	NET%	RAM Usage
VM1	15	23	13	0.6
VM 2	0	0	0	0
VM3	60	67	58	0.4
VM 4	54	56	72	1

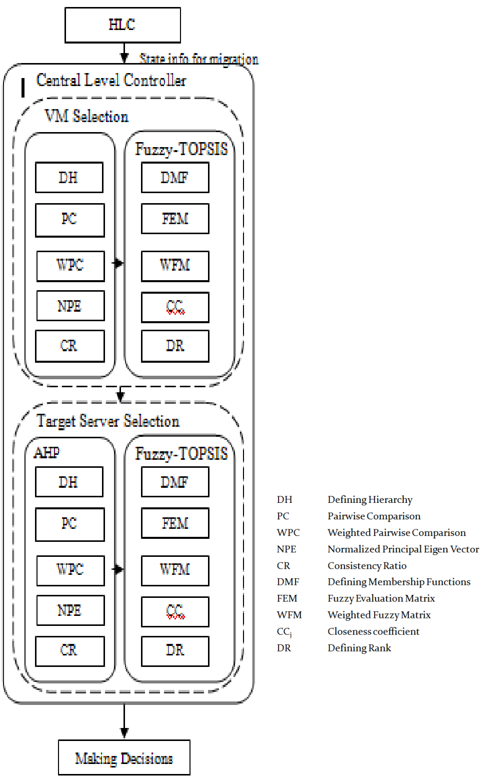

Figure 2. Main Steps of CLC

5.1 VM Selection

In this resource pool, most of the servers are running CPU intensive applications. Therefore, CPU usage percentage is the most preferable criteria for the data center's administrator.

5.1.1 AHP

The pairwise comparison matrix of the criteria is shown in Table 4. Priority vector and their consistency check are shown in Table 5, 6 and 7. The weights of the criteria are needed to be consistent. For example, if criteria A is 3 times more preferable than criteria B and criteria B is 2 times more preferable than criteria C, then it can be assumed that criteria A is 6 times preferable than criteria C. If it is not, inconsistencies occur. If they are not consistent, it will be affected on the rankings of fuzzy-TOPSIS as the contents of priority vectors are used in the calculation of weighted fuzzy matrix.

Table 4. Pairwise comparison matrix

	C1	C2	c3	C4
C1	1	3	5	2
C2	0.5	1	2	0.5
C3	0.2	0.5	1	0.5
C4	0.5	2	2	1

Table 5. Weighted pairwise comparison matrix

	C1	C2	c3	C4
C1	0.455	0.462	0.5	0.5
C2	0.227	0.154	0.2	0.125
C3	0.0909	0.077	0.1	0.125
C4	0.227	0.308	0.2	0.25

Table 6. Normalized principal Eigen vector

Criteria	Eigen Values
C1	0.479
C2	0.177
C3	0.098
C4	0.246

Table 7. Values of λ_{max}, CI, RI, CR

λ_{max} = **4.168** (Eigen Value)
CI = 0.0561 (Consistency Index)
RI = 0.9 (Random Index)
CR = 0.062 < 0.1 (Consistency Ratio)

5.1.2 Fuzzy-TOPSIS

Weights of the criteria chosen for VM selection are consistent as shown in Table 7. After then, ranks of the virtual machines are determined by using fuzzy TOPSIS method. The triangular fuzzy numbers related with these variables are shown in Table 8.

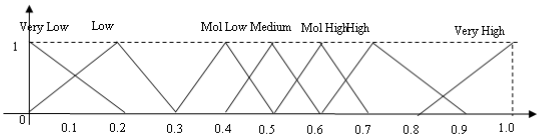

Figure 3. Membership functions of linguistic variables

Table 8. Linguistics values and fuzzy numbers

Fuzzy Membership Regions	
Very Low	(0,0,0.2)
Low	(0.1,0.2,0.3)
Mol Low	(0.3,0.4,0.5)
Medium	(0.4,0.5,0.6)
Mol High	(0.5,0.6,0.7)
High	(0.6,0.7,0.9)
Very High	(0.8,1,1)

Established Fuzzy evaluation matrix of alternatives VM by linguistic variables is shown in Table 9. Table 10 consists of the triangular fuzzy numbers which are equivalent of Linguistic variables. After the fuzzy evaluation matrix was determined, fuzzy weighted decision table is obtained. Using the criteria weights calculated by AHP, the weighted evaluation matrix is established with Eq. (3). The resulting fuzzy weighted decision matrix is shown in Table 11. According to Table 11, it is seen that the elements are belonged to the closed interval [0, 1]. Thus, we can define the fuzzy positive solution (FIPS, A^*) and the fuzzy negative-ideal solution (FINS, A^-) as $\tilde{v}_i^* = (1,1,1)$ and $\tilde{v}_i^- = (0,0,0)$ for benefit criterion, and $\tilde{v}_i^* = (0,0,0)$ and $\tilde{v}_i^- = (1,1,1)$ for cost criterion.

In this case, criteria 1, 2 and 3 are defined as benefit criteria and criteria 4 is regarded as cost criteria. Criteria 4, RAM usage by each VM is defines as 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.

Table 9. Fuzzy evaluation matrix by linguistic variables

	C1	C2	C3	C4
VM1	Low	Mol Low	Low	High
VM2	Very Low	Very Low	Very Low	Very Low
VM3	High	High	Mol High	Medium
VM4	Mol High	Mol High	High	Very High

Table 10. Fuzzy evaluation matrix by triangular fuzzy numbers

	C1	C2	C3	C4
VM1	(0.1,0.2,0.3)	(0.3,0.4,0.5)	(0.1,0.2,0.3)	(0.6,0.7,0.9)
VM2	(0,0,0.2)	(0,0,0.2)	(0,0,0.2)	(0,0,0.2)
VM3	(0.6,0.7,0.9)	(0.6,0.7,0.9)	(0.5,0.6,0.7)	(0.4,0.5,0.6)
VM4	(0.5,0.6,0.7)	(0.5,0.6,0.7)	(0.6,0.7,0.9)	(0.8,1,1)

Table 11. Weighted fuzzy matrix

	C1	C2	C3	C4
VM1	(0.048,0.096,0.144)	(0.053,0.071,0.089)	(0.009,0.019,0.029)	(0.148,0.172,0.22)
VM2	(0,0,0.096)	(0,0,0.035)	(0,0,0.196)	(0,0,0.049)
VM3	(0.887,0.335,0.431)	(0.106,0.124,0.159)	(0.049,0.059,0.069)	(0.098,0.123,0.148)
VM4	(0.239,0.287,0.335)	(0.089,0.106,0.124)	(0.059,0.069,0.088)	(0.197,0.246,0.246)

The distance of each alternative from D^* and D^- can be calculated using Eq. (5) and Eq. (6).Then similarities to the ideal solution are calculated using Eq. (7). The CC_j values are summarized in Table 12. Based on the CC_j values, the ranking of the alternatives are made in the descending order VM3, VM4, VM1 and VM2. If the weight of the criteria has not consistency, the appropriate VM that should be migrated can change.

Table 12. Fuzzy-TOPSIS result for D_j^*, D_j^- and CC_j

Alternatives	D^*_j	D^-_j	CC_j
VM1	2.997	1.018	0.253
VM2	2.979	1.071	0.264
VM3	2.588	1.424	0.355
VM4	2.767	1.241	0.309

Table 13. Weighted ranking

Rank	Weighted CC_j	Weighted Rank
1	0.355	VM3
2	0.309	VM4
3	0.264	VM2
4	0.253	VM1

5.2 Target Server Selection

The same steps of calculation are taken in target server selection. Six criteria are used for this case as shown in Table 14. In this case, three criteria, CPU usage percentage, RAM usage percentage and NET usage percentage are defined as benefit criteria and CPU cycle, RAM capacity, Net BW of the physical host are defined as cost criteria.

Table 14. Criteria for target server selection

Criteria	Definition	Type
C1	CPU%	Benefit
C2	RAM%	Benefit
C3	NET%	Benefit
C4	CPU Clock Speed	Cost
C5	RAM Capacity	Cost
C6	Net Bandwidth	Cost

In this phase, the lowest rank is regarded as the least loaded server. Therefore, it is chosen as the destined server for migration. The last three criteria are used as cost criteria because the physical machine with the higher value of them is capable for higher load. Most loaded server is in the top rank and the least loaded server is defined as the optimal server for migrated VMs. Step by step calculations by using AHP are shown in Table 15, 16, 17, and 18 .

5.2.1 AHP

Table 15. The pairwise comparison matrix for criteria

	C1	C2	C3	C4	C5	C6
C1	1	3	5	1	3	5
C2	0.33	1	2	0.33	1	2
C3	0.2	0.5	1	0.2	0.5	1
C4	1	3	5	1	3	5
C5	0.33	1	2	0.33	1	2
C6	0.2	0.5	1	0.2	0.5	1

Table 16. Weighted normalized pairwise comparison criteria

	C1	C2	C3	C4	C5	C6
C1	0.0327	0.333	0.313	0.327	0.333	0.313
C2	0.108	0.111	0.125	0.108	0.111	0.125
C3	0.065	0.056	0.063	0.065	0.056	0.063
C4	0.327	0.333	0.313	0.327	0.333	0.313
C5	0.108	0.111	0.125	0.108	0.111	0.125
C6	0.065	0.056	0.063	0.065	0.056	0.063

Table 17. Values of λ_{max}, CI, RI, CR

λ_{max}	6.0049
CI	0.002
RI	1.24
CR	0.002<0.1

Consistency ratio of the pairwise comparison matrix is calculated as 0.002 < 0.1. So the weights are shown to be consistent and they are used in the selection process.

5.2.2 Fuzzy-TOPSIS

When Fuzzy-TOPSIS is used for the target server selection according to the collected data, the final result is shown that Physical host 3 is the most overloaded server and Physical 2 is the least loaded server. Therefore, in this case Physical host 2 is chosen as the destined server. Step by step calculations by using AHP are shown in Table 19, 20, and 21.

Table 19. Fuzzy evaluation matrix by linguistic variables

	C1	C2	C3	C4	C5	C6
PM1	Low	Mol Low	Low	Mol High	Medium	Medium
PM2	Very Low	Very Low	Very Low	Medium	Medium	High
PM3	Very High	High	Mol High	Medium	Medium	Medium
PM4	High	Mol High	Very High	Very High	Mol Low	High
PM5	Mol High	High	Low	Very High	Very High	Medium

Table20. Fuzzy-TOPSIS result for D_j^*, D_j^- and CC_j

Alternatives	D_j^*	D_j^-	CC_j
PM1	3.163	2.848	0.474
PM2	3.235	2.794	0.463
PM3	2.845	3.164	0.527
PM4	3.034	2.976	0.495
PM5	3.161	2.849	0.475

Table 21. Weighted ranking

Rank	Weighted CC_j	Weighted Ranks
1	0.527	PM3
2	0.495	PM4
3	0.475	PM5
4	0.474	PM1
5	0.463	PM2

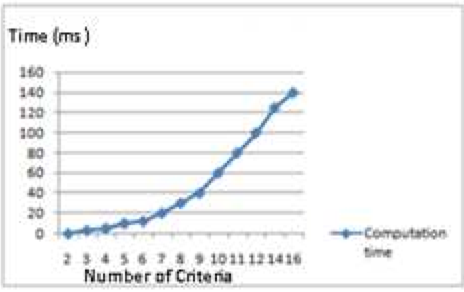

Figure 5. Number of criteria and computation time

Figure 5 shows the time requirement when number of criteria increase. Because of the trade-off between computational time, complexity and accuracy, we chose sufficient number of criteria for decision making of migrations.

6. Conclusion and future work

In this paper, we have discussed the usage the combination of AHP and fuzzy-TOPSIS method for the decision support of CLC. AHP is used for consistency checking of weights of the criteria for VM selection and target server selection phases. Ranks of the alternative VMs and alternative physical hosts are ordered by using Fuzzy-TOPSIS. Because of Fuzzy-TOPSIS, vagueness, uncertainties of virtualized data center are easily described in the model. Four criteria are used for VM selection and six criteria are used for target server selection according to the data center's administrator experience of this environment. According to the computational overhead, the proper numbers of criteria are chosen. Too much criteria make large size of matrixes and it will make more computation time. Numerical evaluation shows that the chosen criteria are suitable to accurate migration decision. In the future, we would like to complete our proposed for the operation of VLC and HLC controllers. By combining these controllers harmoniously, efficient automatic resource management system for the virtualized data center will be developed.

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