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Energy-Saving Virtual Machine Placement in Cloud Data Centers

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Abstract—**In cloud data centers, different mapping relationships between virtual machines (VMs) and physical machines (PMs) cause different resource utilization, therefore, how to place VMs on PMs to improve resource utilization and reduce energy consumption is one of the major concerns for cloud providers. The existing VM placement schemes are to optimize physical server resources utilization or network resources utilization, but few of them focuses on optimizing multiple resources utilization simultaneously. To address the issue, this paper proposes a VM placement scheme meeting multiple resource constraints, such as the physical server size (CPU, memory, storage, bandwidth, etc.) and network link capacity to improve resource utilization and reduce both the number of active physical servers and network elements so as to finally reduce energy consumption. Since VM placement problem is abstracted as a combination of bin packing problem and quadratic assignment problem, which is also known as a classic combinatorial optimization and NP-hard problem, we design a novel greedy algorithm by combining minimum cut with the best-fit, and the simulations show that our solution achieves better results.**

Keywords- **Cloud Data Center, Virtual Machine Placement, Multiple Resource Constraints, Energy Optimization**

I. INTRODUCTION

Cloud computing provides users with on-demand, flexible, reliable and low-cost services, and the infrastructure of these services is cloud data centers [1]. On the other hand, cloud providers need to construct and manage data centers with low cost. With the increasing scale of cloud computing, power consumption is undoubtedly growing, which increases operation cost. The related report from Microsoft [2] shows that the physical resources in data center (e.g. CPU, Memory, Storage, etc.) will account for 45% of the total cost, and energy costs will account for 15%; according to [3], in the past five years, energy consumption in data centers doubled; it has been estimated that infrastructure and energy cost will be 75% of the overall operating cost by 2014 in a data center [4]. Therefore, how to reduce energy consumption is becoming an important issue in cloud data centers.

Now, most of physical servers in cloud data center use virtualization technology. Based on the service level agreement (SLA) with cloud providers, the tenants order a group of virtual machines (VMs) which are placed in different hosts and have communication between each other. Each VM requires a certain amount of resources, such as CPU, memory, storage, bandwidth to maintain application performance isolation and security. Moreover, virtualization technology runs multiple virtual servers on the same physical machine (PM), which is helpful to improve resource utilization and then to reduce energy consumption. Correspondingly, virtualization can also help cloud managers achieve orderly and on-demand resource deployment, which provides an effective solution to the flexible resource management and low energy consumption.

For public cloud with virtualization, one of its major services is infrastructure as a service (IaaS), such as Amazon EC2 [5]. Tenants pay to rent VM based on SLA, and cloud providers take advantage of flexible VM placement on PM to optimize resources allocation so as to meet tenants' demands. Since different resource utilization is caused by different mappings between VMs and PMs, a major concern of cloud providers is how to place multiple VMs demanded by tenants onto physical servers efficiently so as to minimize the number of active physical resources and energy consumption, and correspondingly, operation and management costs will be reduced. Nowadays, VM placement is becoming a hot issue.

Recent studies on VM placement are mostly limited to the constraints of the PM resources [6-9], such as CPU, memory and storage limit etc., but the optimization of network resources is less concerned. For example, Verma *et al.* [6] propose to reduce the number of hosts for reducing energy consumption by using VM placement. However, these studies do not consider the impact of network topology and current communication traffic. Actually as the scarce resources in data center, network resources have a direct impact on application performance [10]. Other studies on VM placement are either to improve network resource utilization or to optimize network traffic in data center [11-13], but some problems still exist : 1) these studies simply assume that sufficient resources are provided when placing VM to physical server, and neglect the energy consumption of PM. 2) these studies concern less with the heterogeneous features of PMs and VMs.

In fact, two factors should be considered at the same time when it comes to VM placement: the allocation of physical server resources, such as CPU, memory, storage etc., and the optimization of network resources. Thus our paper proposes a VM placement scheme in consideration of multiple resource constraints. When meeting the constraints of PM resources (CPU, memory, etc.) and network link capacity, cross-optimizing VMs placed on PMs can maximize the resources utilization of PMs and

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network elements, and improve the throughput of the devices, which makes the idle physical device in sleep state and minimize the number of active physical servers and network elements, thus finally to reduce energy consumption in cloud data center.

The optimization of physical server by VM placement is abstracted as a bin packing problem (BPP), while the optimization of network resources by using network topology and communication traffic is abstracted as quadratic assignment problem (QAP). As we all know, BPP and QAP both are NP-hard problem [14, 15], so we attempt to minimize network communication traffic, the less traffic in the network, the fewer the number of the active network elements. For a classic multi-objective optimization problem, not only the number of PMs should be reduced, but also the number of network elements should be reduced to reduce the energy consumption in cloud data center. Based on this, we propose a new method by combining hierarchical clustering with best fit (BF) to solve the multi-objective optimization, which involves in two steps: firstly, hierarchical clustering algorithm enables the VMs with large traffic to be placed on the same PM or the same access switch, thus to reduce the network traffic. Secondly, according to the clustering results, we apply BF algorithm to optimize the PM resources. Simulation results verify that our proposal achieves good results.

Our paper is organized as follows: Section II presents the related work. VM placement is described and modeled in Section III. Section IV puts forward VM placement algorithm. The simulation is shown in Section V. Section VI concludes the paper.

II. Related Work

There are two focuses on VM placement problem. One is to consider how to place VM with the constraints of the physical servers' limited resources [6-9]. Verma *et al.* [6] dynamically re-adjust server's location and consider the cost of application migration and energy, with a simple algorithm, and it shows that dynamic migration technology realizes low energy cost. Bobroff *et al.* [7] adopt prediction techniques while minimizing the number of active PMs, and present mechanism for dynamic migration of VMs based on a workload forecast. Cardosa *et al.* [8] reset max, min, share and other VM parameters to meet users' demands and to provide a new PM resource allocation method; it consolidates multiple VM onto PM to improve resource utilization and reduce power consumption. Wang *et al.* [9]consider the consolidation of VM bandwidth with PM bandwidth as a random packing NP-hard problem (SBP) , it shows certain size of VM is loaded onto a PM with a probability distribution, and the goal of optimization is to minimize PM number. However, [6-9] only consider PM optimization, and ignore network resource. The PM optimizing schemes above consider either CPU constraints [6] or PM bandwidth constraints [9] , and they neglect network topology and VM communication traffic.

The other type is to consider how to place VM to optimize network resources [11-13]. Meng *et al.* [11]are to improve the network scalability in data center network with a traffic-aware VM placement scheme. By optimizing VM's location in the PM host, the traffic between VMs is related to the network cost, and VMs with large traffic can be placed on nearby PMs to reduce the total network traffic. Mann *et al.* [12] propose to reduce energy consumption by VM migration technology and network routing optimization. Biran *et al.* [13] focus on satisfying the traffic demands of the VMs in addition to CPU and memory requirements. The paper strives to allocate a placement that not only satisfies the predicted communication demand but is also resilient to demand time-variations. These solutions only assume to meet physical servers needs, and they only optimize network resources and neglect physical server resource.

Currently, some studies consider how to place VM with the multi- resource constraints [16-18]. Singh *et al.* [16] take advantage of VM migration technology to change VM's position in PM so as to achieve load balance in system performance, and such problem is abstracted as multi-dimensional knapsack problem. However, this approach is different from our proposal, and our goal is to improve resource utilization, so it is not suitable to apply the approach in [16]. Chaisiri *et al.* [17] propose an optimal VM placement algorithm. This algorithm can minimize the cost spending in each plan for hosting VMs in a multiple cloud provider environment under future demand and price uncertainty. It is also different from our optimization goal. Jiang *et al.* [18] study a joint tenant (e.g., server or virtual machine) placement and routing problem to minimize traffic costs. These two complementary degrees of freedom—placement and routing—are mutually-dependent, but they neglect the optimization of overall communication traffic in data center network.

III. Design and Model

A. Problem Description and Symbol Definition

In IaaS, cloud providers lease resources to tenants, and tenants subscribe SLAs with cloud providers to guarantee the service performance. For tenants, the crucial service is to meet the requirements of quality of service (QoS) and guarantee the application performance, while for cloud providers, based on SLA, the key objection is to maximize profit, improve resource utilization and save energy. Without violating SLAs, that is, in the premise of ensuring application performance, the main concern for cloud providers should be how to design VM placement scheme to improve the physical resource utilization in the resource pool and reduce the number of active PMs and network elements, then to reduce the hardware investment and power consumption, and finally to reduce the operation cost in data center.

In cloud data center, there are two ways of VM placement: static and dynamic. Static placement means cloud providers consider to place VM on idle PM to satisfy the demands based on VM resource vector. Static placement is generally applied for initial VM placement, if there is large load fluctuation, the application performance will be degraded. Dynamic placement means VMs demand to be readjusted when VMs do not correspond with PMs in the initial calculation, especially when VMs meet load fluctuations in running so that VMs will dynamically migrate or change the size. Correspondingly, the cost of migration will be increased. The other potential problems include business interruption, the increase in network traffic and possible violation of SLAs. Thus, it is not feasible to frequently migrate a large number of VMs in a data center. Typically, static and dynamic placements are two essential stages for VM placement problem. Our paper mainly focuses on static placement.

In order to guarantee the performance of the application, a load estimation algorithm should be needed in order to convert effective load into the VM demands. Estimation algorithm may be based on historical resource utilization (e.g., days, weeks, months), with the measurement of these historical data, the required workload can be converted into the server size [19] and the required number. With the estimation algorithm, resource demand supporting operation as well as VM vector can be more accurately obtained. Meanwhile, the traffic matrix between the VMs should be correctly estimated [11, 20] , under the condition of low cost, traffic statistics depend on the hypervisors of switch or VM.

When tenants submit multiple jobs to the data center, each job requires multiple VMs. VM i resource demand is a d-dimensional vector $\vec{\mathbf{S}}_i$, and each dimension represents certain type of VM resources (such as CPU, memory, storage, bandwidth etc.).Vector $\vec{\mathbf{S}}_i = \{S_{i,1}, S_{i,2}, \dots, S_{i,d}\}$, d is the number of types of resources , for example , S_{i2} represents the desired value of the resource type 2 in VM i , and the vector set $\{\vec{\mathbf{S}}_i\}_{i=1,\dots,N}$ represents all VM resource demands, the main meanings of the symbols are given in Table Ⅰ.

TABLE I. KEY NOTATIONS AND THEIR MEANING

Symbol	Description
M	Number of PMs , indexed by $m = 1, .., M$
N	Number of VMs , indexed by $i = 1..N$
$\vec{\mathrm{H}}_m$	d dimensional resource vector of PM m ,its value $\{\mathrm{H}_{m,1}, \mathrm{H}_{m,2}, \dots, \mathrm{H}_{m,d}\}$, d is the number of resource types
$\vec{\mathbf{S}}_i$	d dimensional resource vector of VM i its value $\{\mathrm{S}_{i,1}, \mathrm{S}_{i,2}, \dots, \mathrm{S}_{i,d}\}$
Y_m	Binary variable , 1 indicates PM m is in the activation status ; 0 indicates that PM m is sleep
$X_{i,m}$	Binary variable , 1 indicates VM i is placed on the PM m , whereas is 0
A	Communication traffic matrix, $(a_{i,j})_{N\times N}$ is the traffic between VM i and VM j
B	Communication cost matrix B, The communication cost is equivalent to the number switch that the traffic between PMs traverse.

B. Problem Formalization

1. Optimization Network Resources

For the optimization of network resources, our objective is to minimize traffic in cloud data center, and we abstract this problem as QAP. We converge the large traffic between VMs onto the same PM or on the same switch. If the total communication traffic in network is smaller, then the number of network elements (switches, link, etc.) will be reduced, and the other idle network elements will be in a sleep state, finally the power consumption will be reduced. Here, we use network communication traffic to describe network power consumption. The proposal not only can save energy of the network element, but also improve the application performance.

Traffic matrix $A = (a_{i,j})_{N\times N}$, communication cost matrix $B = (b_{m,p})_{M\times M}$, $a_{i,j}$ is the traffic between VM i and VM j; $b_{m,p}$ represents the communication cost between PM m and PM p, and communication cost is equivalent to the number switch that the traffic between PMs traverse. The greater the communication cost, the higher the network energy consumption.

The objective function can be formally expressed as:

$$min \;\; cost_{net} = \sum_{i,j=1}^{N} a_{i,j} b_{m,p} \qquad (1)$$

$$Subject\ to \;\; \sum_{i=1}^{N} X_{i,m} \cdot \vec{S}_i \preccurlyeq Y_m \cdot \vec{H}_m ,\ \forall m$$

$$\sum_{j=1}^{N} X_{j,p} \cdot \vec{S}_j \preccurlyeq Y_p \cdot \vec{H}_p ,\ \forall p$$

$$\{X_{i,m}, X_{j,p}\} \in \mathcal{F}$$

2. Optimization Server Resources

Our focus is mainly on how to minimize number of active PMs when different sizes of VMs are mapped to PMs. Here, we use the number of PMs to describe server energy consumption. The fewer PMs will bring less energy consumption.

We define $X_{i,m}$ as a binary variable, expressed as

$$X_{i,m} = \begin{cases} 1 & if \text{ VM } i \text{ on PM } m \\ 0 & other \end{cases} \qquad (2)$$

Set $\mathcal{F}$ represents a set of all VM:

$$\mathcal{F} = \left\{ \{X_{i,m}\} \middle| X_{i,m} \in \{0,1\},\ \sum_{m=1}^{M} X_{i,m} = 1, \forall i \right\} \qquad (3)$$

$\sum_{m=1}^{M} X_{i,m} = 1$ means each VM can only be placed on a single PM. VM placement be formalized as follows :

$$min \;\; cost_{ser} = \sum_{m=1}^{M} Y_m \qquad (4)$$

$$Subject\ to \;\; \sum_{i=1}^{N} X_{i,m} \cdot \vec{S}_i \preccurlyeq Y_m \cdot \vec{H}_m ,\ \forall m$$

$$\{X_{i,m}\} \in \mathcal{F}$$

Binary variable $Y_m \in \{0,1\}$ shows PM m is running or to be activated. The constraint is the number of multiple

VMs placed on a PM cannot exceed the number of corresponding PM resources.

3. Optimization Physical Resources Energy

$$min\ \ cost_{net} + r \cdot \ cost_{ser} \quad (5)$$

This is a multi-objective optimization problem, and it is also a classic combinatorial optimization problem.

IV. VM Placement Algorithm

Generally the solution to such multi-objective optimization and NP-hard problem is intelligence optimization algorithm, such as genetic algorithms, ant colony algorithm etc., which may lead to poor time performance and instability compared with greedy algorithm [21]. So we propose a new method by combining hierarchical clustering with BF to solve the multi-objective optimization, which involves in two steps: firstly, hierarchical clustering based on minimum cut algorithm enables certain VMs to cluster together to finally minimize the total network traffic. Secondly, according to the clustering results, we apply BF to optimize the PM resources and reduce PM's energy consumption. The inputs are network topology, link capacity, traffic routing, traffic demand, VM resource vector and PM resource vector, and the output is the mapping of VMs on the PMs.

A. Hierarchical Clustering Algorithm based on Minimum Cut

Most of the data centers are three-tier architecture [22]. For network topology and network traffic between the VMs, the VMs with the large traffic should be placed on the same PM or with the same switch to ensure the application performance and reduce the number of the network equipments. We solve QAP with hierarchical clustering algorithm based on the traffic between VMs.

Let G=(V, E) be a connected undirected graph, where V is a collection of VMs , E is the traffic between VMs. Hierarchical clustering is achieved by using the minimum cuts in graph G. Given a node set $Q \subseteq V$, $\delta(Q)$ denotes the set of all edges with one end in Q and the other end in $V \backslash Q$. A cut consists of all edges that have one end in Q and the other end in $V \backslash Q$, where Q is a node set such that $Q \neq \emptyset$ and $Q \neq V$; that cut is denoted $(Q, V \backslash Q)$.

Let every edge $ij \in E$ be assigned a nonnegative capacity $c(ij)$.The capacity of a cut is defined as the sum of the edge in it, i.e., $c(Q, V \backslash Q) = \sum_{ij \in \delta(Q)} c(ij)$ .The minimum cut problem is to find a cut in G with smallest capacity.

The minimum cut of G is expressed by binary tree T(V). For a binary tree T(V), left subtree TL is the node in Q, its weight is the sum of the edge in Q, $W(TL) = \sum_{ij \in Q} c(ij)$, right subtree TR is the node of V\Q, the weight is the sum of the edge in V\Q, $W(TR) = \sum_{ij \in V \backslash Q} c(ij)$, if W(TL) < W(TR) , swap the left sub- tree TL with right subtree TR, which means the VMs traffic of left subtree TL is larger than that of right subtree. Leaf nodes of a binary tree T (V) represent only one VM, the branches mean a collection of VMs after clustering. This algorithm is defined as MC-BT. The algorithm is described in Algorithm 1.

Algorithms 1 MC-BT algorithm

```
Input: Graph G=(V,E)
Output : Binary Tree T(V)
Initial cut S
Initial Binary Tree T
While G has more than one node do
    Pick two distinct node s and t
    Compute a minimum capacity cut δ(S′) separating s and t
    If c(S′, V\S′) < C
        C ← c(S′, V\S′) and S← S′;
    Endif
    Left subtree TL ← G_s(V),compute W(TL)
    Right subtree TR ← G_t(V), compute W(TR)
    if W(TL) < W(TR)
        TL ↔ TR; G_s ↔ G_t
    Endif
    Replace G by G_s and G_t
Endwhile
Output T(V)
```

B. VM Placement Algorithm based on BF

T(V) is obtained from MC-BT. Preorder tree traversal results in a vector called VMlist, which consists of the successive leaf nodes of tree T. We place all VMs nodes using VMlist. As can be seen in the previous discussions, VM neighbors have larger traffic between each other in VMlist. The larger distance between a pair of VM nodes is, the smaller traffic between them is.

By BF algorithm, we place different sizes of VM nodes in VMlist into the corresponding PMs. We place VMs in VMlist sequence. For a new VM, we search from the first PM until finding the one which best matches this new arrival. Only when all active PMs cannot accommodate this VM, a new PM can be allocated.

The time complex of BF is $O(n^2)$, and space complexity is $O(n)$. This algorithm is defined as Best Fit with hierarchical clustering algorithm (BF-HC). The algorithm is described as algorithm 2.

Algorithms 2 BF-HC algorithm

```
Input: physical resource vector PMlist, binary tree T(V).
Output : matrix X of the mapping between VM and PM
initialize  VM vector group VMlist (preorder tree traversal T(V) leaf
  nodes sequentially into the VMlist)
Foreach VM_i in VMlist do
  Foreach PM_m in PMlist do
    If (isAllocable(VM_i, PM_m) and PM_m.spare < PM_best.spare)
      Best← m
    Endif
  Endfor
  X_{i,m} ← 1,  Allocation(VM_i, PM_best)
Endfor
Output  X
```

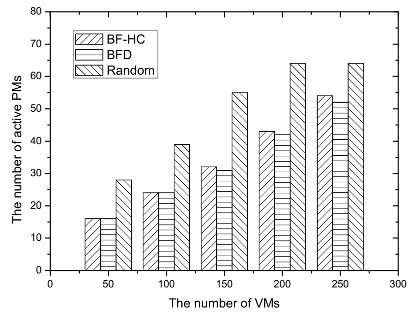

Figure 1. Algorithm comparison in PMs number

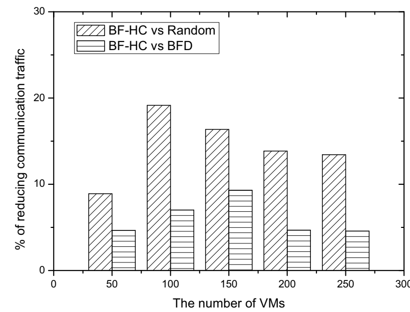

Figure 3. Communication traffic of fat-tree topology in global traffic pattern

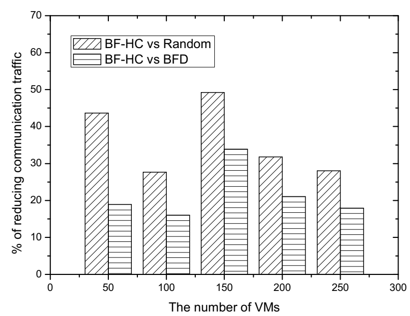

Figure 2. Communication traffic of tree topology in global traffic pattern

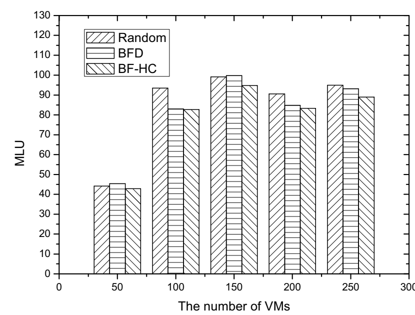

Figure 4. MLU of tree topology in global traffic pattern

V. EVALUATION

A. Simulation Setup

We use C++ to develop our BF-HC simulation. The most common approximation algorithm to solve the BPP are next fit decreasing(NFD), first fit decreasing (FFD) and best fit decreasing (BFD) [23] , but we select BFD in common use, together with random algorithm, to compare with our BF-HC .

Data center is a common hierarchical topology, such as multi - rooted tree [22], VL2 [24], fat-tree [25] etc, so our simulation choose the most common tree topology and fat-tree, and routing policy is the shortest path protocols.

There are three basic inputs in our simulation: VM resource vector group, PM resources vector group and traffic matrix between the VMs. For VM resource vector group, Amazon EC2 [26] provides a flexible choice to meet different application needs, so we select the VM size and configuration similar to Amazon EC2. PM resources offered by cloud providers can be divided into two kinds: to be homogeneous and to be heterogeneous. The homogeneous kind is to allocate a group of commensurate PM, and each PM is provided in the same size. The heterogeneous kind refers to that some VMs have already been placed on the PM, and the new VMs are allocated in the remaining PMs resources or physical resources are provided with different sizes for inconsistent procurement time. For VM traffic matrix, our experiments take the traffic patterns in [11, 20].

B. Simulation Result

1) Global Traffic Pattern

Global traffic pattern means that each VM is likely to communicate with other VMs at a certain rate. With the different scale of the VMs in the data center, a group of VMs 50, 100,150,200 and 250 are selected. They have different CPU size, memory capacity, storage capacity and network bandwidth. We compare random algorithm, BFD and BF-HC to these five groups of VM to calculate number of active PMs, the traffic and the maximum link utilization.

Figure 1 shows the number of active PMs for various types of algorithms; BFD and BF-HC require less PMs than random algorithms. The effect of BFD is better than that of BF-HC, because BFD is designed according to the size of VMs while BF-HC is designed for traffic aggregation between the VMs, but BF-HC requires almost the same number of PMs as BFD.

Figure 2 and Figure 3 respectively show the traffic difference by comparing BF-HC with BFD and random algorithms in the tree topology and fat-tree topology. In the tree topology, the traffic by BF-HC is averagely decreased by 21% compared with BFD, and decreased by 36%

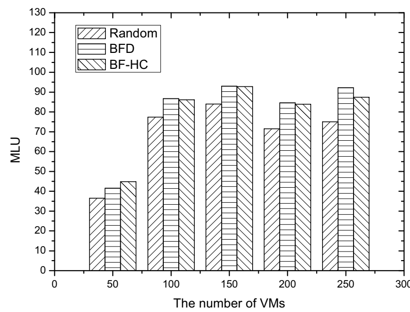

Figure 5. MLU of fat-tree topology in global traffic pattern

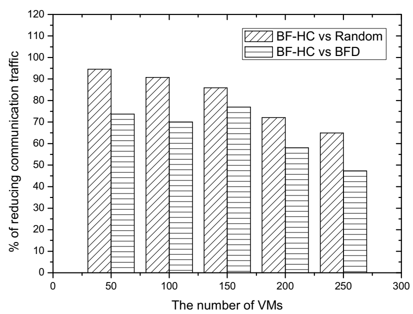

Figure 6. Communication traffic of tree topology in partitioned traffic pattern

compared with random algorithms; in fat-tree topology,the traffic by BF-HC is averagely decreased by 6% compared with BFD, and decreased by 13% compared with random algorithms, so it can be seen that in the global traffic patterns BF-HC has better effect in the tree topology.

Figure 4 and Figure 5 respectively show the maximum link utilization (MLU) differences by comparing BF-HC with BFD and random algorithms in the tree topology and fat-tree topology. In the tree topology, there is almost no MLU difference among BF-HC, BFD and random algorithms; in fat-tree topology, random algorithm shows lower MLU due to its balanced traffic distribution.

2) Partitioned Traffic Pattern

Partitioned traffic pattern refers to each VM is likely to communicate with the VMs within the same group, and there is no communication traffic with the other VMs outside. Reducing number of active PM is similar to global traffic pattern.

Figure 6 and Figure 7 respectively show the traffic difference by comparing BF-HC with BFD and random algorithms in the tree topology and fat-tree topology. In the tree topology, the traffic by BF-HC is averagely decreased by 65% compared with BFD, and decreased by 81% compared with random algorithms; in fat-tree topology, the traffic by BF-HC is averagely decreased by 29% compared with BFD, and decreased by 41% compared with random algorithms, so it can be seen that in

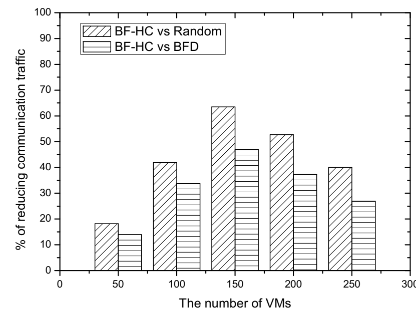

Figure 7. Communication traffic of fat-tree topology in partitioned traffic pattern

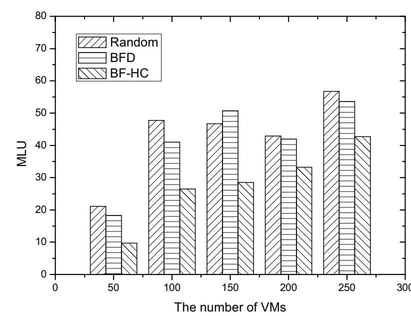

Figure 8. MLU of tree topology in partitioned traffic pattern

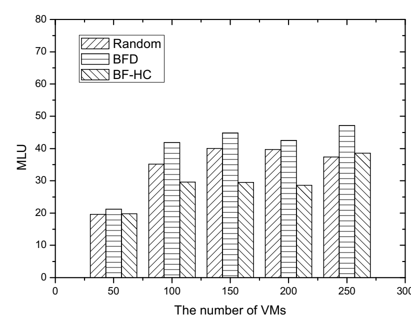

Figure 9. MLU of fat-tree topology in partitioned traffic pattern

partitioned traffic pattern BF-HC has better effect in the tree topology, and BF-HC in the partitioned traffic pattern achieves better optimization than in the global traffic patterns .

Figure 8 and Figure 9 respectively show the maximum link utilization (MLU) differences by comparing BF-HC with BFD and random algorithms in the tree topology and fat-tree topology. In the tree topology, MLU by BF-HC is lower compared with BFD and by random algorithms; and when contrasting with BFD, MLU by BF-HC is averagely decreased by 12 % in partitioned traffic pattern, so BF-HC can also have influence on network MLU.

It can be seen from the simulations that in partitioned traffic pattern, BF-HC shows obvious advantages in the optimization of the total traffic and MLU, which is due to the feature of traffic matrix aggregation itself. Our BF-HC just makes use of this feature to optimize the traffic in data center.

VI. Conclusion and Future Work

VM placement problem is one of the challenging tasks in cloud data centers. In our VM placement scheme, we consider multi-resource constraints of PM and attempt to save energy. We propose to optimize both PM energy and network elements energy. We abstract VM placement problem as a combination of multi-constraint BPP and QAP. After analyzing the advantages and disadvantages of the selected algorithm, we propose a novel greedy algorithm by combining minimum cut with the best-fit. In the case of little change in the number of PMs, the simulations show that our solution achieves better results for optimizing network traffic.

The main objective in our paper is to reduce the number of physical resources to save energy consumption in data center, but there are still some potential problems. On the one hand, if more and more VMs are placed on the same PM, physical resources will overload, which would have influence on VM resource expansion; on the other hand, if more network traffic aggregates on the same network link, network links utilization will be improved, but it will also cause network congestion problems. Thus, our next research direction will concentrate on two aspects: how to reach a relative balance among resources utilization and load in VM placement, and how to minimize the migration cost to realize VMs' dynamic placement.

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