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An Energy-efficient Genetic-based Algorithm for Virtual Machine Placement in Cloud Datacenter

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***Abstract*—This paper presents an optimal energy efficient virtual machine (VM) placement in cloud datacenter environment. VM placement is how to map requested VMs on underlying physical machines so at least an objective function is satisfied. In this paper, VM placement is formulated as an optimization problem so total power consumption of datacenter is minimized. Generally, virtual machine placement problem is NP-hard. Therefore, a genetic-based meta-heuristic algorithm is proposed to figure the problem out. To gain concrete results, several scenarios are considered. The implementation of scenarios demonstrated that proposed GA-based algorithm outperforms other heuristics in terms of number of active servers and total power consumption of datacenter.**

Keywords—Cloud computing; VM placement; Genetic algorithm

I. INTRODUCTION (*Heading 1*)

Information technology (IT) is footstone of an organization apart from business objectives [1]. It tackles barriers to business entry. So, information technology outsourcing (ITO) is a new paradigm to delegate organizations' business process to third party [2-3]. In this line, the total cost of ownership (TCO) can be mitigated; therefore, the organization only concentrates on its core business instead of IT device procurement. On the other hand, well-known cloud service providers such as Amazon [4], Google [5], Salesforce [6], etc. are responsible for this mission. In addition, these companies leverage virtualization technology to co-host as many VMs as possible on the same physical machine to recline their business internal costs [7]. The task of mapping *n* virtual machines (VMs) to *m* physical machines (PMs) is called VM-placement subject to total VM's utilization does not exceed underlying PM's resource utilization [8]. Figure 1 illustrates VM placement module. In fact, users deliver their requests in terms of CPU, Memory and bandwidth need. An optimal VM placement module must co-host requested VMs to the minimum number of active servers.

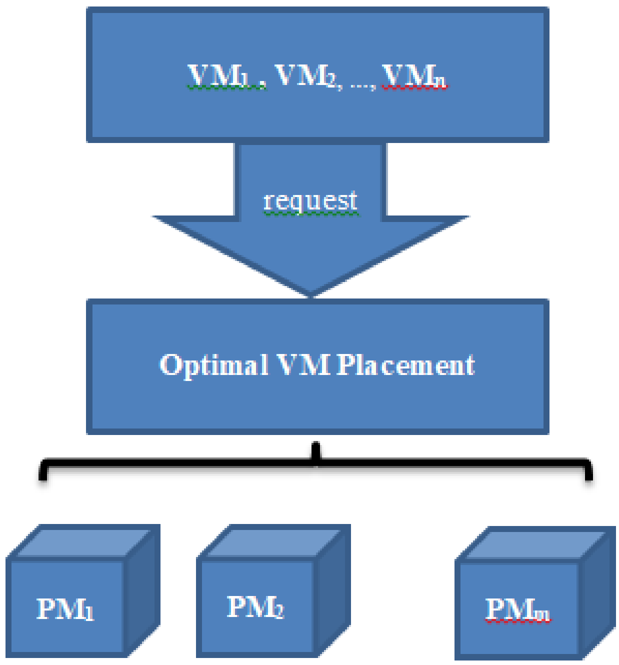

Fig. 1. VM placement module

Formally, VM placement problem is transformed to classic bin-packing problem, where the bins are PMs and items are VMs. Note that all of physical resources are multiplexed between VMs. Also, PM's or physical server's utilization is calculated by sum of VMs' utilization which are currently placed on a specified PM. Generally, VM placement problem belongs to NP-hard problems, where a need for extending meta-heuristic algorithm is tangible. Nowadays, energy consumption is the first concern in cloud datacenter after security challenges. Thus, cloud providers try to lower down their operational expenditures (OPEX) by applying efficient VM placement. Authors in [9] reported a many TWh electricity usage of modern datacenters in which one of the main reason is owing to underutilized resource; so optimal VM placement can obviate the problem. Aldossary et al. have been presented an energy-aware cost prediction algorithm to solve virtual machine placement in cloud environment; their work was based on resource utilization and power consumption prediction [10]. This paper presents an optimal VM placement strategy with energy-efficient approach. To do so, the three-tier datacenter topology and datacenter energy model are introduced; then, an optimal energy-efficient VM placement model is presented. To solve the combinatorial problem, the GA-based algorithm is extended. The experimental result proves the effectiveness of proposed meta-heuristic algorithm.

II. DATACENTER TOPOLOGY

In this paper, the canonical three-tier datacenter topology is adopted. In the lowest level in the access level PMs encapsulated in racks are connected via switches. As switches have limited capacity and for the sake of lowering the cost, the second layer or aggregation network is considered to extend the scale of the network of switches; finally, core network is applied to connect with internet. The optimal VM placement must map VMs on PMs in access network. Figure 2, depicts Tree-shape of datacenter which includes Access Network at the lowest level, Aggregation level at the middle and the core network at edge level.

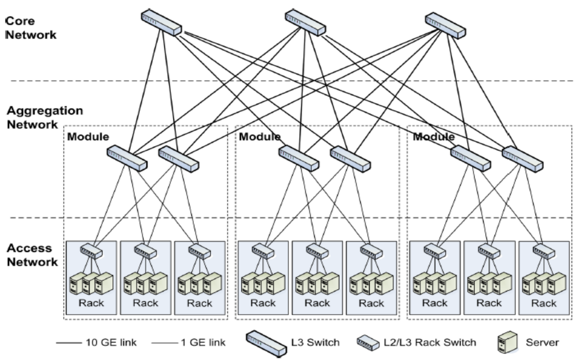

Fig. 2. Three-tier Datacenter Architecture [11]

III. SERVER AND DATACENTER POWER CONSUMPTION MODELS

Server power consumption is attained by power usage of CPU and other peripheral devices. Inasmuch as the big portion of system power usage is relevant to CPU one, in this paper power usage of other peripherals are ignored. However, power consumption are linearly related to its utilization [12]. The equation (1) is shown the power usage model of *k*-th physical server.

$$P_k = \left(P_k^{Max} - P_k^{min}\right) \times U_k^{CPU} + P_k^{min} \qquad (1)$$

Where P_k^{Max}, P_k^{min} and U_k^{CPU} are power consumption of crest utilization, power consumption of the lowest server utilization and measured server utilization respectively. Moreover, power consumption can be ignored in case server utilization is near zero. Here, we consider homogeneous datacenter which contains HP ProLiant G5 servers with P_k^{Max}=135 and P_k^{min}=100 watts. Moreover, its CPU and Memory capacity are 5320 MIPS and 4GB respectively [13]. For the sake of simplicity, in this paper normalization method is applied. The VM placement can be considered two dimensional bin-packing problem with 1×1 size; figure 3 depicts 2D bin-packing problem. For instance, VM which needs 2660 MIPS and 1GB memory is 0.5×0.25 size. One important thing to mention is that this paper takes 90 percent of server capacity because in practice using 100 percent of server capacity leads performance degradation and increases service level agreement violation (SLAV) rate.

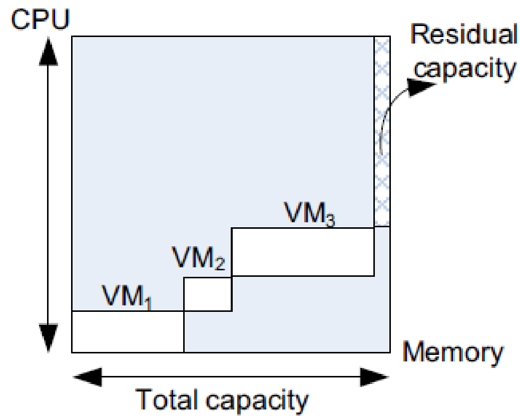

Fig. 3. 2D bin-packing problem [14].

In addition to, datacenter power usage (*DPU*) model is attained via equation (2):

$$DPU = \sum_{k=1}^{m} P_k \,.\, x_k \qquad (2)$$

Where decision variable x_k is one if *k*-th server is active, otherwise it is zero. Moreover, variable *m* is the number of PMs in datacenter.

IV. PROPOSED GENETIC ALGORITHM

As mentioned earlier, VM placement problem is NP-hard in nature. To deal with the combinatorial problem, we have extended a genetic-based algorithm. This section is dedicated to the definition of gen, chromosome, fitness function and other GA operators. Finally, figure 6 depicts proposed energy-efficient GA-based VM placement in forthcoming sub section.

A. *Problem statement*

This paper concentration is to map requested n VMs to m PMs so that the whole datacenter power usage is minimized. It can be mathematically formulated as equation (3):

$$min(DPU) = \min \sum_{k=1}^{m} \left(P_k^{Max} - P_k^{min}\right) \times U_k^{CPU} + P_k^{min} \,.\, x_k \qquad (3)$$

Subject to: $x_k \in \{0,1\}$

Server Utilization $\leq$ $Predetermined\_Threshold$

B. *Gens, Chromosome and Fitness Function*

In this paper, we are given a list of *n* VMs' request to be hosted on *m* homogeneous PMs. The goal is to launch as minimum number of PMs as possible; because this way is a promising technique to lower down power consumption. Anyway, we take a vector with the length of n as chromosome and each gen can take an integer number belong to [1..*m*]. For instance, chromosome (1,2,2,1,5) shows that VM_1 and VM_4 are placed on PM_1, VM_2 and VM_3 are placed on PM_2 and VM_5 is placed on PM_5. Moreover, the rest of PMs set to switch off. The fitness function of this GA algorithm which directly depends on optimization problem is as equation (4):

$$\text{Fitness (Chromosome)} = DPU = \sum_{k=1}^{m} \left(P_k^{Max} - P_k^{min}\right) \times U_k^{CPU} + P_k^{min} . x_k \quad (4)$$

C. Crossover Operator

In this paper, we define new crossover operator. When we determine some individuals by roulette wheel operator with better fitness and their mate for crossover; then we apply crossover algorithm which the figure 4 shows.

Algorithm1. Crossover
Input: two chromosomes $Ch1=a_1a_2\dots a_n$, $Ch2=b_1b_2\dots b_n$.
Output: $Ch3=c_1c_2\dots c_n$

```
F1=Fitness(Ch1)
F2=Fitness(Ch2)
For i=1 To n do
   Generate random number 0 ≤ r ≤1.
   If r> F1/(F1+F2) then
      ci= bi
   Else
      ci= ai
   EndIf
EndFor
Return Ch3
```

Fig. 4. New Crossover operator

D. Mutation Operator

The mutation operation is utilized to avoid getting stuck in local optimum. Therefore, the mutation operator is defined as figure 5 shows.

Algorithm2. Mutation
Input: a chromosomes $Ch1=a_1a_2\dots a_n$.
Output: $Ch2=b_1b_2\dots b_n$.

```
Ch2=Ch1
Generate random number 1 ≤ r ≤n
Generate random number 1 ≤ r ≤m.
Ch2(n)=m
Return Ch2
```

Fig. 5. New Mutation operator

E. Selection Operator

For the reason of chromosome selection to produce new generation, we can apply tournament or roulette wheel algorithm. However, we apply roulette wheel one and bias it so the chromosome with higher fitness function is probable to be selected. Our roulette wheel algorithm is such as in [15].

F. Energy-efficient GA-based VM placement

In this sub section, figure 6 depicts a new energy-efficient GA-based VM placement algorithm.

Algorithm3. Energy-efficient GA-based VM placement
Input: Request list of *n* VMs and *m* PMs
Output: The optimal individual as a solution

Generate initial Population as *Pop* with *PopSize* as its size
While the termination criteria is not met do
  -Calculate the fitness of each individual in *Pop* based on equation (4)
  -Select a mate for each individual in *Pop* by applying roulette wheel operation
  -Crossover: Generate an individual per each parents
  -Mutation: Generate mutated individuals with pre-determined probability
  -Randomly Apply Local Search for packing VMs on minimum PMs
  -Put all of new generation in Temp
  -Select *PopSize* of better individuals form Temp and put it in *Pop*
Endwhile
Return the best individual

Fig. 6. Energy-efficient GA-based VM placement algorithm

V. EVALUATION

To evaluate the effectiveness of our proposed meta-heuristic genetic algorithm, we define different scenarios. However, we produce a random dataset representative of VMs requests. As we have deal with normalization in section 3, this belongs to (0..1] for CPU and Memory needed. Also, we compare our work with famous heuristic algorithm first fit decreasing (FFD) and a random-based algorithm in terms of number of used server and total power consumption in datacenter. We define four different scenarios 16, 32, 64 and 128 VMs requests to be hosted on 16, 32, 64 and 128 PMs respectively. Figure 7, proves that our proposed method beats FFD and Random algorithm in term of used (active) servers.

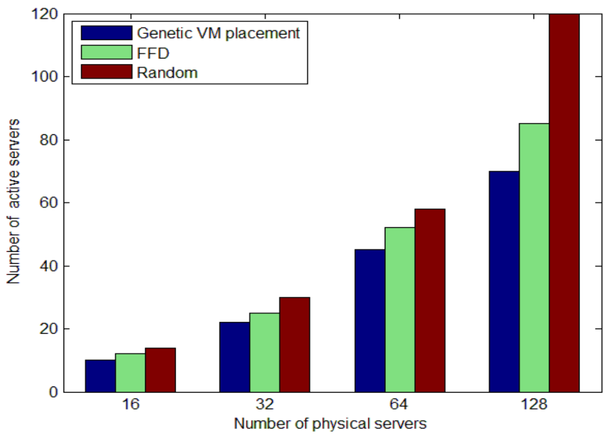

Fig. 7. Comparison of proposed algorithm against other heuristics in term of active server

Moreover, figure 9 illustrates datacenter total power consumption for each scenario. As this figure depicts; we can conclude that energy-efficient GA-based meta-heuristic algorithm carefully explore search space and smartly place VMs into minimum number of PMs; consequently, total power consumption is the minimum as possible. In the other words, the proposed method outperforms against other heuristics.

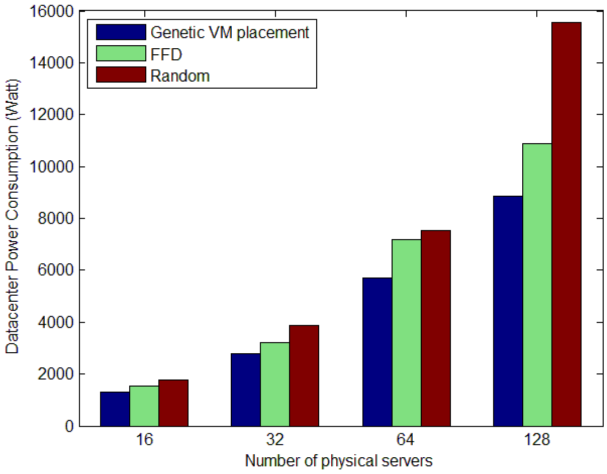

Fig. 8. Comparison of proposed algorithm against other heuristics in term of total power consumption

VI. Conclusion

This paper presents an optimal VM placement algorithm on Tree topology which is three-tier in nature. As VM placement problem is NP-hard, a Genetic-based meta-heuristic algorithms has been developed. To reach a concrete results, different experimental settings have been done. Implementation of different scenarios proves that our proposed approach beats other heuristics in terms of active server and datacenter total power consumption.

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