Game-Theory based Approach for Virtual Machine Placement in Cloud Data Centers

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Abstract : The resource on demand facility of cloud computing attracts various kinds of users to access the resources based on their Quality of Service (QoS) require- ments. The QoS differ from user to user where some users prefer time over money and vice versa. This work considers two types of users i.e. (i) deadline users (time over money) and (ii) non-deadline users (money over time) allocated to respective Virtual Machine (VM). However, managing the placements (mapping) of such different VMs into hosts (physical machines) is always an essential role in cloud data centers with objective to reduce energy usage and residual resource. This paper proposes a Game-theory approach to place two types of users' VMs optimally in a cloud data center environment to reduce energy usage, resource wastage, and Service Level Agreement (SLA) violations. The VM migration plan considers fair migration among user VM type, SLAs, and resource utilization as well. The game is modeled with hosts as a player, VMs as a strategy, and the player's playoff is represented by energy consumption and resource utilization. The focus of the proposed algorithm is to maximize the playoff of each player in the game to achieve the objectives. The data center's energy consumption is minimized by the proposed algorithm, thus satisfying the Quality-of-Service (QoS) criteria of users to comply with the SLAs. The as- assessment of the proposed approach is performed using the CloudSim toolkit and compared with other participant VM placement approaches. The experimental findings indicate that the proposed approach reduces energy consumption, SLA violations while making efficient use of resources.

Keywords: *Game theory; VM placement; Energy consumption.*

I. INTRODUCTION

Cloud Data Centers (CDC) are designed to satisfy the increasing requirement of computing resources from numerous domains. The dynamic features of the CDC enable users to get on-demand computing resources based on desires towards performance, business goals, etc. Generally, CDC is formed on a large scale by deploying a large number of servers in one place, and keeping up such huge infrastructure consumes a colossal sum of energy, operational costs and forces a vast amount of carbon impression on the climate.

The rapid growth of information communication technology (ICT) industry rises the demand of cloud infrastructure, cloud services and data centers. Due to this resource management of data centers has be- come complex and high energy consuming [1]. The records states that PMs/servers consumes largest energy amongst other parts [2]. However, in the year 2017, ICT has able to emit 2.5% carbon of that global emission. In fact the data center's carbon emission is increased to 45% in 2020 from last decade, while the research community assess that CO_2 emission would rise upto 14% of that global emission by 2040 [3].

With this increasing cost of energy, it is imprudent to keep the CDCs under-utilized, which would shockingly happen somewhat without care- fully organizing the CDC. In the interim, the IT business organizations are going through a shift of paradigm towards utilizing the CDC infrastructure to increase or support their business. The clients of CDC may additionally use the provisioned computing resources to give QoS-specific service. It is challenging for CDC to provide QoS-specific computing resources and at the same time maximizing resource utilization and revenue with less operational cost. Virtualization is the vital technology of cloud computing to improve the resource management of CDC by enabling the creation of several virtual platforms on a single physical machine where the service provider can fully utilize the potential of hardware components. The single virtual platform is called a Virtual Machine (VM). The different types of VM can be configured by the service provider with its quantity of resources in terms of CPU, memory, storage, etc.

The group of users that demands their work to be completed within the specified time are classified as deadline users and the group of users who demands their work to be completed within a specified budget but not within the time limit are classified as non- deadline users. The allocation of such users to respective VMs is defined as deadline VMs and non-deadline VMs. Because of the number of re- source needs for various types of VMs, considerable resource fragments will be generated while hosting the VMs on PMs. Therefore, it is essential to place VMs optimally with limited available PMs that im- proves system performance and effective utilization of resources with negligible fragments in the PMs and also reduces the energy cost of CDC. In the past, various approaches have been proposed to reduce energy consumption in cloud data centers. However, the VM placement approaches with considering user constraint have some shortcomings. The PMs are also defined as hosts (i.e. PM and host keywords are identical). Motivated by such a straight VM placement problem, this research work on the VM placement approach is based on two types VMs

(i) Deadline-VMs and (ii) Non-deadline VMs. This work employs the game theory-based algorithm for the VM placement problem to address the afore- mentioned issues.

A. Contributions

The following are the key contributors to the work.

1) A Cooperative Game Theory (CGT) with complete information is proposed to place VMs op- timely among available hosts. A cooperation game is modelled for consolidating two types VMs on a single host which does not affect the QoS requirements and violates the SLAs of both users.
2) The game is modelled with hosts as a player, VMs as a strategy, and the player's playoff is represented by energy consumption and re- source utilization.
3) The proposed approach of VM placement is implemented and assessed using the CloudSim toolkit upon synthetic workload. The outcomes of the proposed approach are compared with the outcomes of *First Fit Decreasing* and *Best Fit Decreasing* heuristic algorithms.

The CGT brings the cooperativeness and achieves equilibrium state among two types of VMs to share the suitable host. The proposed approach takes the advantage of non-deadline VMs as they do not hold restriction compared to deadline VMs. The overall problem is to consolidate more VMs into fewer hosts that achieves fair allocation and minimizes the number of active hosts in the CDC and maintains maximum resource utilization of host. The remain- ing under-utilized hosts are put to sleep mode or turned off to save energy and operational cost.

B. Motivation

In recent times, cloud data centres are facing one of the virtuous issues of rising energy usage while managing their physical servers (resources). Due to unbalanced resource allocation, host may go under utilized or get over utilized. The efficient utilization of hosts is the key factor to conserve energy and resource, this can be achieved through dynamic VM placement concept. The efficiency of the data center can be increased by enhancing resource utilization by placing more number of VMs into less number of hosts. The effective placement of both types VMs within available host with required QoS and SLA is challenging task. Efficient VM placement solutions within polynomial time, however, are difficult to achieve. According to the study, the Game theory approach is best suitable for constraint specific re- source allocation. Therefore, the cooperative Game Theory (CGT) with complete information is employed to accomplish the optimal solution for the VM placement problem that improves the overall utilization of resources and energy of the CDC.

II. RELATED WORKS

Virtual machine management is a noteworthy issue in data centers to save energy and resource wastage. The great number of VM placement approaches have been studied in [4].The authors in [5] proposed energy aware heuristic algorithm to place the VMs in hybrid cloud environment.

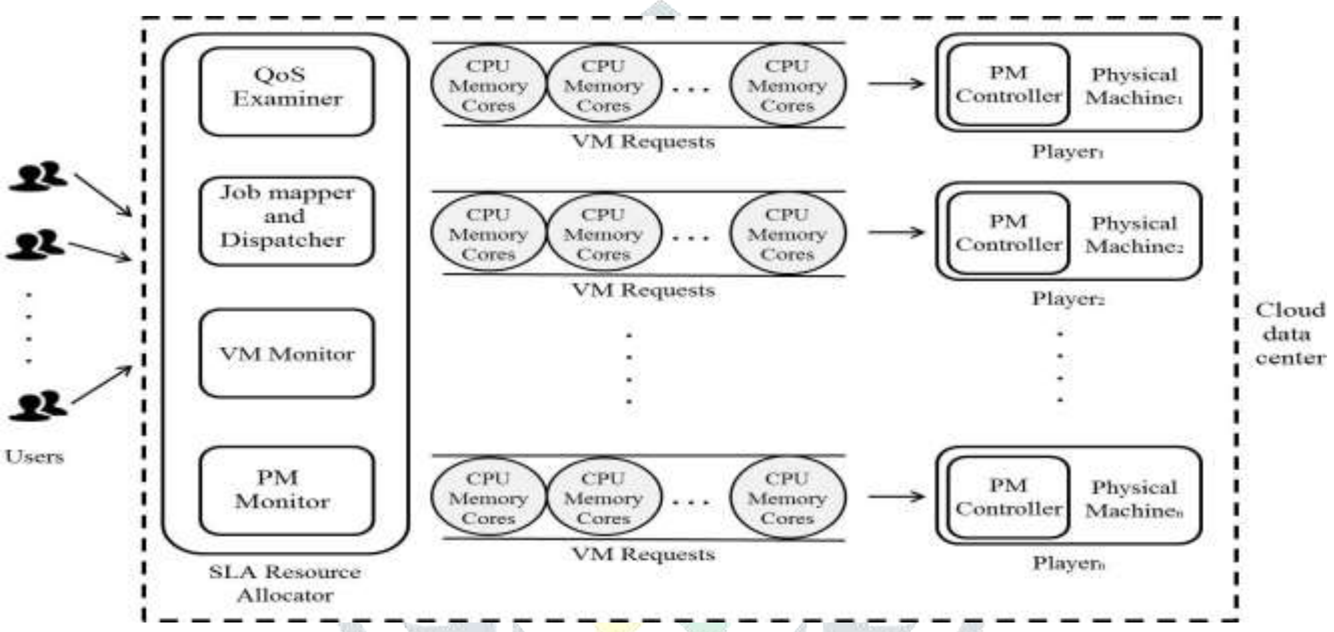


Fig. 1: Proposed sytem model.

The QoS based migration strategy is used to select the VM to migrate from one host to another. The results are obtained by adjusting the thresholds of the host to achieve the energy efficiency. The extensive game theory is adopted in [6] to solve the VM allocations problem in cloud computing and the analysation states that the optimal solution is found theoretically. The work concentrated on initial allocation of VMs into hosts. In order to improve the energy efficiency of cloud, the authors in [7] address QoS based VM scheduling problem which is formalized as multi-objective problem. The author solve the problems using non-dominated sorting Genetic Algorithm III to find optimal VM migration policy while maintain less energy conservation. The author in [8] used greedy algorithm to address the problem of VM distribution across data centers and those are First Fit, Next Fit, Best Fit, Worst Fit and Random allocation. The work obtained better results with Best Fit algorithm. In [9], formulates the problem of VM consolidation as a bin-packing problem and achieved the defined objective to minimize VM migrations and SLA violation by using Best Fit Decreasing (BFD) heuristic algorithm. Furthermore, several more works have been applied modified BFD and heuristics First Fit Decreasing (FFD) algorithms to solve the consolidation issue. Furthermore, in order to reduce the energy consumption of data centers, the authors in [10] extend the bin-packing problem of VM placement with Worst Fit Decreasing (WFD). The static mode of placement is adopted to avoid the VM migrations. The work proposed hybrid job scheduling to the VMs and evaluated over space- shared and time-shared policies in terms of energy consumption, SLA violations and VM migrations parameters. The work in [11] proposed distributed resource allocation approach using Game theory with both operative and non-cooperative policies for the federated clouds. The work demonstrates that the game of mutual allocation (cooperative) provides a greater incentive for service providers to supply services.

III. PROBLEM STATEMENT AND OBJECTIVES

The problem of virtual machine is to find the best strategy (collection of VMs) for each host that reduces the running active host number and consumes less energy while satisfying QoS requirements with expected performance.

The objectives of the work include the following:

1) To reduce the total energy consumption and active hosts of CDC under QoS constraint VMs
2) To classify deadline and non-deadline VMs of CDC for placing into the suitable host
3) Apply cooperative game theory based algorithm to optimally place the all VMs in minimum number of hosts.

TABLE I: Notations

Notation	Description
H	Set of hosts
VM	Set of virtual machines
n	Total number of VMs in set VM
m	Total number of hosts in set H
E_j	Total energy consumption of host j
E_{max}	Maximum energy consumed by host j
k	Minimum energy consumed by host j
$cap(v_i)$	Resource capacity of VM v_i
$R_{cap}(h_j)$	Remaining resource capacity of host j
π^s_{m-1}	A strategy s for host $m-1$
S_{ij}	Matrix of strategy
$\gamma_j(\pi^s_j)$	playoff of energy consumption if host selects s strategy

IV. SYSTEM MODEL

The system is modeled with data center while inheriting the characteristics of Infrastructure-as-a- Service cloud model.

A data center is comprised with a set of PMs/hosts at bottom line of system. Each host is configured with CPU, memory, disk storage and bandwidth. The proposed system model is presented in Fig. 1 and consist of four modules namely QoS examiner, Dispatcher, VM monitor, and PM monitor.

1) ***QoS Examiner***: Examines the required QoS of the users at the beginning of the submission of jobs and make a decision of acceptance or rejection of user request. If the user is get accepted then SLAs are formed between the user and provider by the resource allocator of SLA segment.
2) ***Job mapper and Dispatcher***: The job map per assigns the QoS constrained users jobs to respective VMs and dispatcher maps the corresponding VM to available host in the data center.
3) ***VM monitor***: It is responsible of VM's status in terms of CPU and memory utilization. The stats of the VM monitor helps while placing the VMs into hosts.
4) ***PM monitor***: It holds the status of the host resource utilization. The allocation VMs should not keep the host in overloaded or underloaded state.

All hosts as players in this cooperative game pick the VMs as strategies of VM placement problem to maximize their individual playoff in terms of minimizing energy consumption and residual resource.

A. Resource model

Suppose a host is accommodating VMs that are processing the respective QoS requests and it is defined as VM pattern matrix V. The matrix V is a dimension of $xX\,y$ where x denotes the QoS specified VM type requested by user and y specifies the different capacity type of VM.

$$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1y} \\ v_{21} & v_{22} & \cdots & v_{2y} \end{bmatrix} \qquad (1)$$

B. Allocation Model

Given the matrix of VMs, the aim of the VM placement problem is to establish appropriate mapping of VMs to suitable hosts. The possible state of VMs allotment is represented as allotment matrix for the set of available hosts.

$$P_j = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1r} \\ p_{21} & p_{22} & \cdots & p_{2r} \\ \vdots & \vdots & \vdots & \vdots \\ p_{i1} & p_{i2} & \cdots & p_{ir} \end{bmatrix} \qquad (2)$$

where p_{ir} stands for the quantity of resource capacity r is allocated to VM i of host j. The placement or allocation choice is a set of possible placement condition of each host based on the VM pattern matrix.

C. Energy Consumption Model

In most of the cases, the energy consumption of host commonly relies upon the linear function of its CPU utilization rate. Subsequently, the host's CPU utilization rate depends upon the workload applied by the application. The CPU utilization is defined as the ratio of total CPU usage of the host to the total CPU capacity of that particular host. Thus, energy consumption model is given by:

$$E_j = k \times E_{max} + (1-k) \times E_{max} \times U_j \qquad (3)$$

where, E_{max} is the maximum energy consumed by host j when fully utilized and constant k represents energy consumption by host at minimum utilization i.e. underutilized or idle host. U_j denotes the current CPU consumption of host j. The efficiency of energy consumed can be defines as the ratio of total workload gained to the total energy consumed.

$$E_{erg} = \frac{T_W}{E_C}$$

$$E = \frac{U_{cpu}}{\left(k \times E_{\max} + (1-k) \times E_{\max} \times U_{cpu}\right)} \cdot \left(k \times E_{\max} + (1-k) \times E_{mx}\right) \qquad 0 \le E_{erg} \le 1 \qquad (4)$$

Where T_W *and* E_C are the total workload and total energy consumption respectively. The efficiency should falls between 0 and 1. The number near to 1 indicates the resource utilization of hosts is improved.

D. Problem Formulation

A data center is constructed using a set of PMs/hosts denoted as $H = \{h_1, h_2 \ldots, h_m\}$ thus, depending upon the requests a host is eligible to accommodate more than one VM on it. The set of VMs is represented by $VM = \{v_{p1}, v_{p2}, , v_{pn}\}$ where p denotes deadline or non-deadline type VM and n represents the VM number i.e. (i=1,2, , n). The goal of VM placement problem is to optimize the energy cost of the data center by placing the VMs optimally into the available hosts and is formulated as:

$$\min \sum_{j=1}^{m} E_j \qquad (5)$$

Subject to the constraints:

1. Placement constraint:

$$\sum_{j=1}^{m} d_{ij} = 1 \qquad \text{For all (i=1,2,…,n)} \qquad (6)$$

If d_{ij} hold 0, then the corresponding VM I is not hosted in j, else currently the VM I is placed onto j^{th} host.

2. Capacity constraint:

$$cap(v_i) \le R_{cap}(h_j) \quad \text{For all } (d_{ij}=1) \qquad (7)$$

Where $cap(v_i)$ is capacity of VM, and $R_{cap}(h_j)$ is the remaining resource capacity of each host with respect to CPU and memory.

The VMs are placed while meeting all the constraints and prevents redundant allocations. The VMs are placed while meeting all the constraints and prevents redundant allocations.

V. GAME THEORY BASED VM PLACEMENT

This section presents the Game theory based approach for dynamic VM placement that aims to reduce residual resource and energy cost by keeping impartial allocation between users.

A. Cooperative game theory

The game hypothesis is a numerical investigation of the technique that endeavors to decide the collaborations among all game players to guarantee the best results for themselves. In game model, collaboration among different players in which the playoff of every player results is influenced by the choice made by other players. The game is represented by three elements and are as follows

1) **Players**: A game is involved by set of players, in this work, hosts are the players (i.e. total number of players = m). Hosts are the essential decision taker within the frame of the game.

2) **Strategy**: Plan of actions by players at each stage to reach objectives and this work considers VMs are the strategies. Set of strategies is denoted by $S = \{s_1, s_2, , s_q\}$ (l = 1, 2, , p).

3) **Playoff:** The measurement of player's profit and loss based on the action selected by player at certain stage. Energy consumption is considered as the playoff that host obtain while choosing a strategy s_l.

In the scenario of single CDC, it is necessary to form the coalition in such way that hosts should get the strategies of VM placement and corresponding actions will be chosen to maximize the utility of the host. Therefore ,this work adopts the cooperative game theory approach for VM placement in CDC.A game specification is a cooperative game theory that follows congestion game model which enables the set of resources are being shared by set of players. A cooperative game with complete information consist finite set of player (hosts) and every host knows the fact of strategies and the likely playoff. An eligible host is able to locate the possible combination to be satisfied by various sorts of VMs without surpassing the capacity. In this VM placement model, every individual player attempts to opt for the strategy that reduces the residual resource i.e. they select those VMs which maximize the resource utilization and also meet the objective of optimization problem. In order to reduce the energy, the player aims to achieve higher playoff by selecting best strategy. Therefore, optimization problem of game can be given by

$$\max\left(\gamma^{m}(P)\right)$$

While satisfying the capacity constraint. In order to achieve the maximum playoff, every single host in the placement game possibly looks to increase their resource utilization or to decrease the residual resource vice versa. Thus, the maximum host utilization function of host j is formulated as

$$U_{\max} = \max_j \left\{1 - \frac{R_{cap}(h_j) - \sum_i p_{ir}\, j}{T_{cap}(h_j)}\right\} \qquad (8)$$

B. Nash equilibrium

It is the rule in game theory that predicts the out- come of a game played by strategic players with the goal of optimizing their profits. The rule suggests that each player developing strategies to optimize his profit has to consider the strategies developed by Opponents. A player search for solutions to optimize his gain and a state of equilibrium is attained such that no other player experience loss while as summing the strategies of the opponents are unchanged. That is, it suggests that neither of the players will gain from arbitrarily modifying their strategy

Let S be the set of strategies, s_j be any strategy of host j such that,$s_j \epsilon$ S and s_j^* be the strategy of host j of Nash equilibrium. If γ represents the playoff orutility of the placement game under the Nash equilibrium then it holds the condition as follows:

$$\gamma\left(s_j^*, s_{-j}^*\right) \geq \gamma\left(s_j, s_{-j}\right) \epsilon \text{ For all j, } s_j^* \qquad (9)$$

Where s_{-j} is the any strategy and s_{-j}^* is the Nash strategy opted by the opponent host in the placement game. A pure Nash equilibrium strategy merely states that the action performed by each host is the better against the real equilibrium actions taken by the other hosts, and not actually against all the other hosts' potential actions.

Algorithm 1 accepts the list of hosts and VMs and process the initial placement of n VMs on m hosts in best possible way using Equation (8) and produces the best strategy in return by performing the Nash equilibrium. At initial stage without Nash equilibrium, some of the hosts get enhanced their resource usage and some there host may not gain the same efficiency and may left with unused resources. Thus, Nash equilibrium is applied for every single host in the game and presented in Algorithm 2. The congestion game model set all the participating VMs are to be shared by all hosts. In such scenario, each hosts selects subset of VMs combination from the VM set to attain the maximum playoff. In this work, more the playoff vale lesser the energy consumption of corresponding host. Algorithm of Nash equilibrium begins with strategies of m and m-1hosts and process until reach to last host. If the m^{th}host the best strategy which fulfill objective then remaining m 1 hosts looks for remaining subset of resources in order to attain the equilibrium state. At each step, the algorithm yields the best possible strategy for all hosts and are evaluated with their play off. Thus, the algorithm attains equilibrium state at a specific time period in polynomial time.

VI. PERFORMANCE EVALUATION

A. Experimental Setup

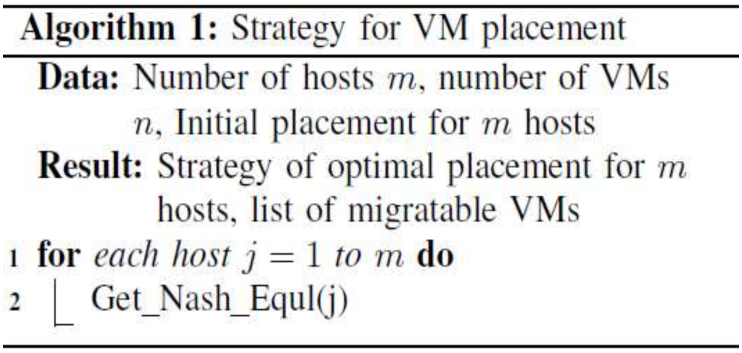
The simulation is conducted using CloudSim [12] to analyze the performance of proposed cooperative game theory approach for dynamic VM placement. The simulation platform is constructed on $i7$ $G1440$ processor. In this experiment, a CDC is designed by creating a total of 600 homogenous hosts and each host is configured with having 100k MIPS rating, memory of 32 GB, and disk size of 1TB. A standard VM configurations of Amazon-EC2 types are simulated i.e. four type of VM instances are used such as small (1 core, 2GB), medium (2 core, 4GB), large (4 core, 8 GB), and extra large (8 core, 16 GB). The poisson process is employed to produce the VM configurations. The user jobs are submitted to the VMs in the form of cloudlets from 200 to 1200. Similarly, maximum of 1200 of both type VMs are created in an interval of 200 randomly. In addition to the proposed algorithm, a dynamic VM placement based on the FFD and BFD are implemented by referring to [13] [14]. The results obtained by the proposed algorithm for VM placement is compared with the results of the dynamic VM placement based on FFD and BFD.

B. Experimental Results

The simulation is conducted to compare the results of the proposed algorithm with FFD and BFD bin packing algorithms in terms of energy consumption and resource wastage. The resource utilization is observed by the proposed algorithm, however, the results are presented in terms of resource wastage for better presentations. The resource wastage is the difference of host's total capacity to utilized capacity. More utilization lesser the wastage of resource.

Fig. 2 presents the hosts have been utilized to execute respective number of VMs. It is observed that linear increase in host numbers as the number of VMs get increase for all approaches considered in the experiment. Yet, the proposed algorithm for VM placement utilized less number of hosts as compared to FFD and BFD. Because of the cooperative strategy between the types of VMs and convergence of Nash equilibrium yields the optimal placement of VMs on less number of hosts. Whereas FFD works on the principle of *first fit* strategy in which the size of the requests are organised in decreasing manner and FFD finds the first suitable host rather than the optimal one that results in non optimal way of placement. Though the BFD finds the first best suitable host to place the VM yet lags in consolidating the VMs in less number of hosts.

Fig. 3 presents the consumption of energy against the number of VMs running in the system. The proposed algorithm consumes less energy compared to FFD and BFD approaches. The other two approaches consumed more energy than the proposed algorithm as they both FFD and BFD utilized more number of host to place the same set of VMs. The efficient way of placing the VMs into the hosts leads the proposed algorithm gain the maximum resource utilization. Thus it wastes less amount of resources as compared FFD and BFD as shown in Fig. 4.



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Algorithm 1: Strategy for VM placement
  Data: Number of hosts $m$, number of VMs
        $n$, Initial placement for $m$ hosts
  Result: Strategy of optimal placement for $m$
          hosts, list of migratable VMs
  for each host $j = 1$ to $m$ do
      Get_Nash_Equl(j)
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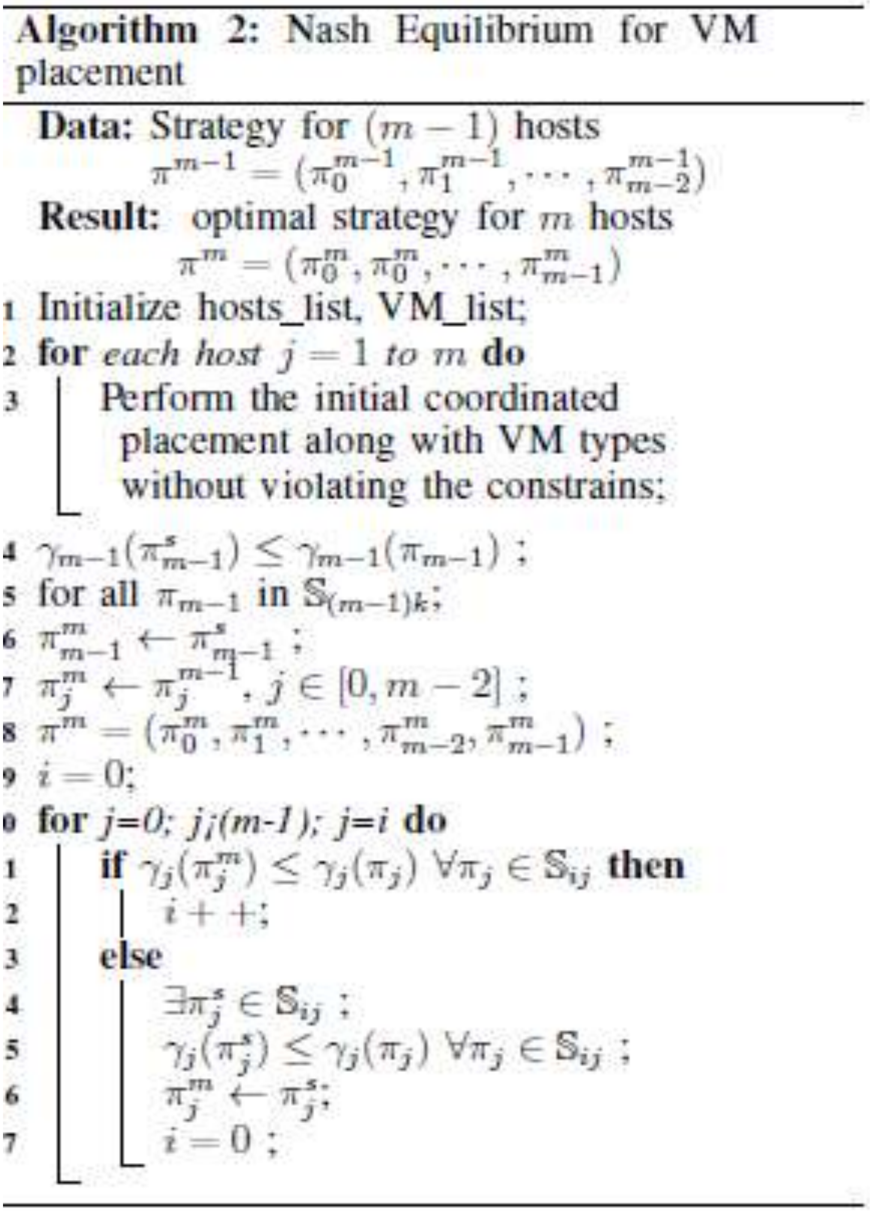

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Algorithm 2: Nash Equilibrium for VM placement
Data: Strategy for $(m-1)$ hosts
      $\pi^{m-1} = (\pi_0^{m-1}, \pi_1^{m-1}, \cdots, \pi_{m-2}^{m-1})$
Result: optimal strategy for $m$ hosts
      $\pi^m = (\pi_0^m, \pi_0^m, \cdots, \pi_{m-1}^m)$
Initialize hosts_list, VM_list;
for each host $j = 1$ to $m$ do
    Perform the initial coordinated
      placement along with VM types
      without violating the constrains;
$\gamma_{m-1}(\pi_{m-1}^s) \leq \gamma_{m-1}(\pi_{m-1})$ ;
for all $\pi_{m-1}$ in $\mathbb{S}_{(m-1)k}$;
$\pi_{m-1}^m \leftarrow \pi_{m-1}^s$ ;
$\pi_j^m \leftarrow \pi_j^{m-1}, j \in [0, m-2]$ ;
$\pi^m = (\pi_0^m, \pi_1^m, \cdots, \pi_{m-2}^m, \pi_{m-1}^m)$ ;
$i = 0$;
for j=0; j¡(m-1); j=i do
    if $\gamma_j(\pi_j^m) \leq \gamma_j(\pi_j) \; \forall \pi_j \in \mathbb{S}_{ij}$ then
        $i++$;
    else
        $\exists \pi_j^s \in \mathbb{S}_{ij}$ ;
        $\gamma_j(\pi_j^s) \leq \gamma_j(\pi_j) \; \forall \pi_j \in \mathbb{S}_{ij}$ ;
        $\pi_j^m \leftarrow \pi_j^s$;
        $i = 0$ ;
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FFD place the VMs in the first suitable host which increase the hosts number to fit the all VMs. BFD also dose good in placing the VMs but not as efficient as game theory approach.

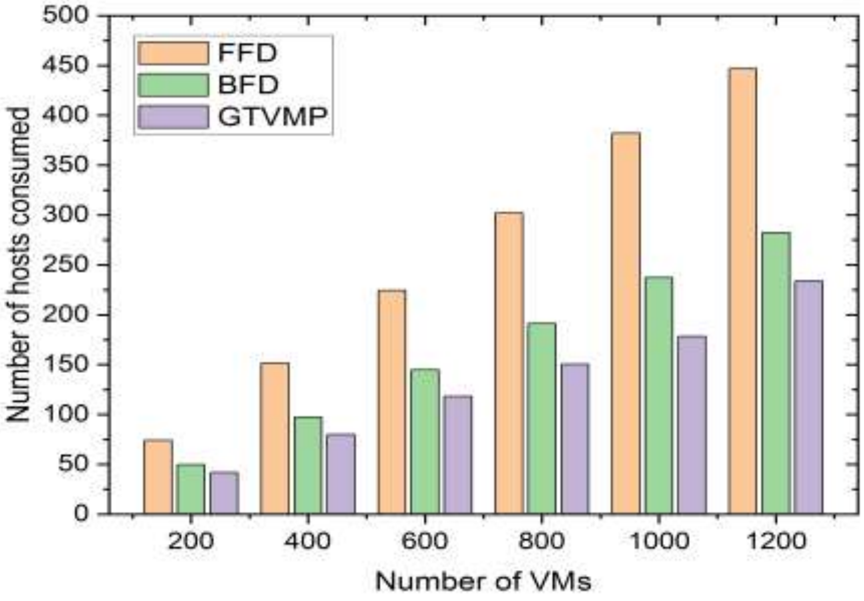

Fig. 2: Number of host utilized per number of VMs.

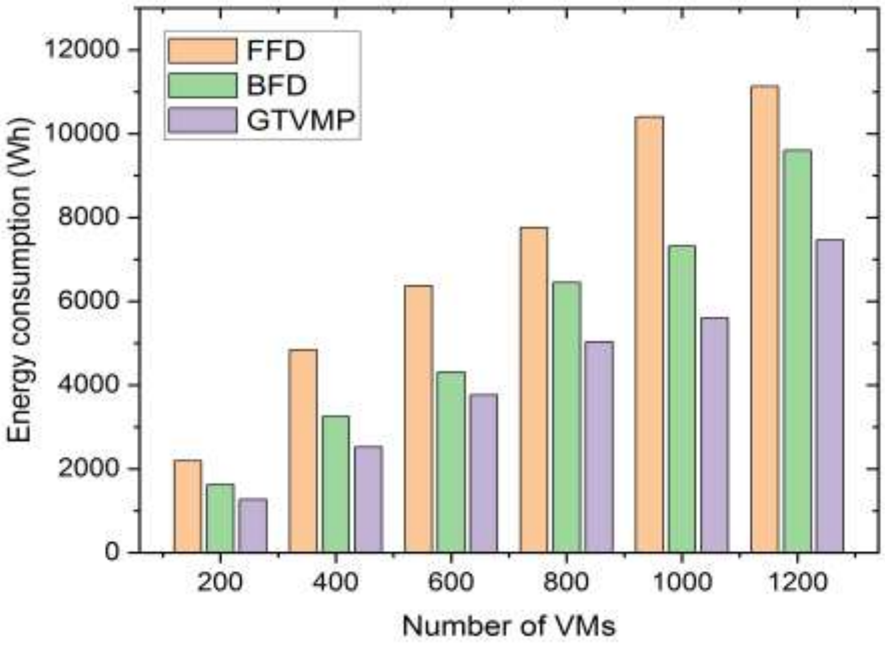

Fig. 3: Energy consumption by three placement approaches over number of VMs.

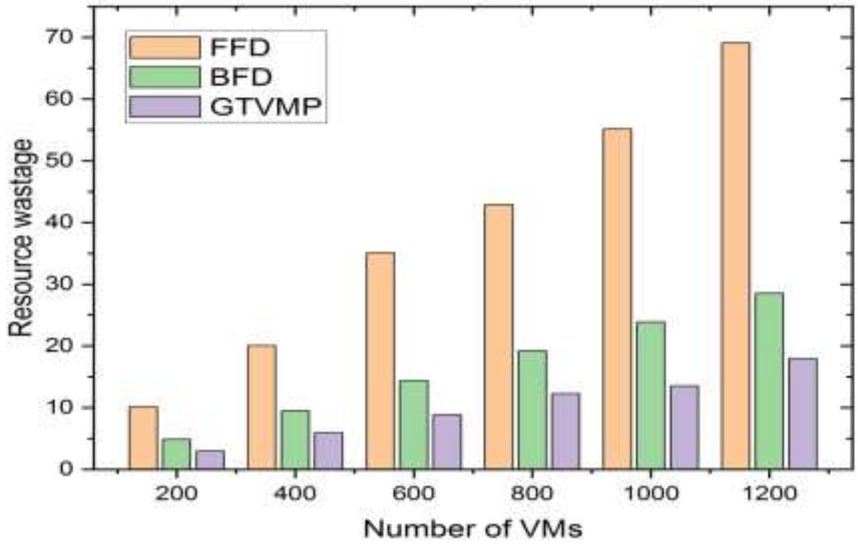

Fig. 4: Resource wastage by three placement approaches over number of VMs.

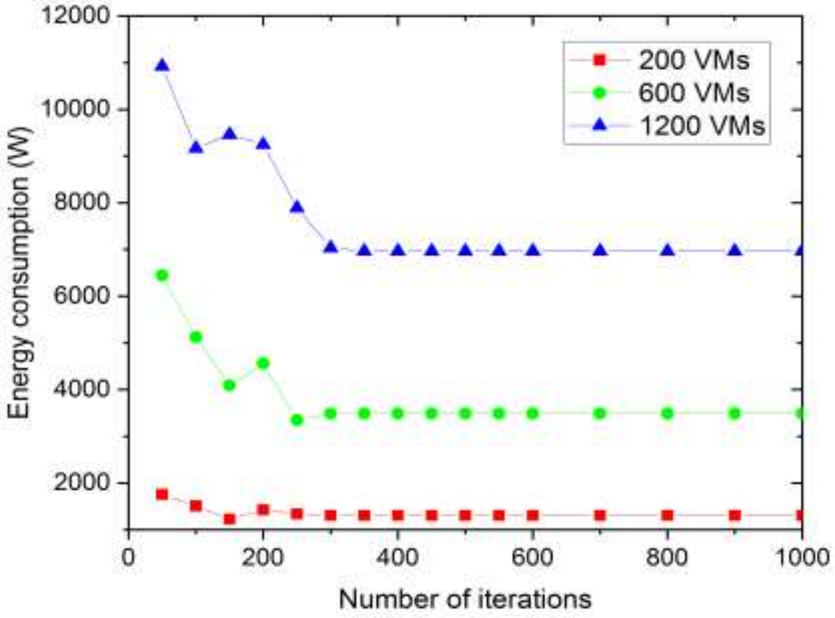

Fig. 5: Energy consumption with number of iterations.

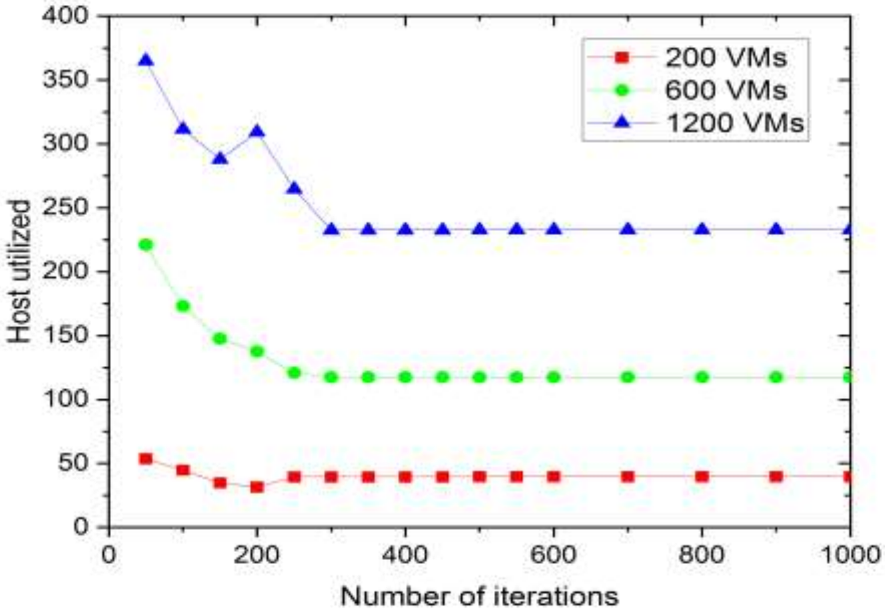

Fig. 6: Host utilized with number of iterations.

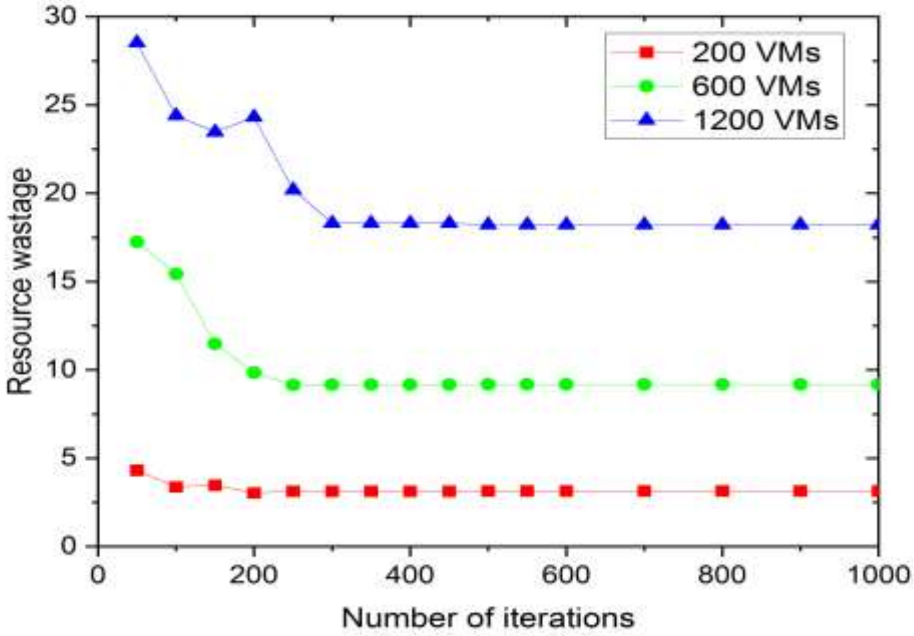

Fig. 7: Resource wastage with number of iterations.

Fig. 5, Fig. 6 and Fig. 7 presents number of iterations used by the proposed algorithm while placing 200, 600 and 1200 VMs in terms of energy consumption, number of host utilized and resource wastage respectively. For all of the three cases like energy consumption, resource wastage and host utilized the convergence took place in between 300 to 350 iterations. The propose algorithm able to find the sub-optimal solution for VM placement at maximum of 350 iterations. The initial values for all the parameters are high at the initial number of iterations. As the number of iterations increased the values of all the parameters get unchanged i.e. it shows the point of convergence. It is observed from the above presented results that the proposed cooperative game theory based VM placement approaches outperforms the FFD and BFD in terms of energy consumption, resource wastage and number of host utilized.

VII. CONCLUSION

Conservation of energy and resources are vital issues in the cloud data center; they need to manage properly to maximize the performance and revenue of service provider. In order to place VMs in the computing resource of the data center effectively, in this paper, a cooperative game theory-based VM placement approach that maps the corresponding VM type (considering the required QoS of the user) to suitable host is proposed. By taking a cooperative approach to the VM placement game system, cooperative game theory produces a reasonably beneficial result. Both the game players have to compromise with each other to find an agreement in order to make the game members comply. The proposed algorithm aims to minimize the overall energy consumption of the data center by minimizing the individual host's energy while maximizing its playoff and each host increases its resource utilization to maximum by selecting the appropriate combination of VMs. The algorithm produces optimal results when every host of the data center reaches the Nash equilibrium state. The results obtained show that the proposed approach performs better as compared with the results of VM placement based on FFD and BFD in terms of energy usage and resource wastage. The algorithms can be further extended with heterogeneity system environment and federated data centers.

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