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TRACTOR: Traffic-aware and power-efficient virtual machine placement in edge-cloud data centers using artificial bee colony optimization

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Summary
Technology providers heavily exploit the usage of edge-cloud data centers (ECDCs) to meet user demand while the ECDCs are large energy consumers. Concerning the decrease of the energy expenditure of ECDCs, task placement is one of the most prominent solutions for effective allocation and consolidation of such tasks onto physical machine (PM). Such allocation must also consider additional optimizations beyond power and must include other objectives, including network-traffic effectiveness. In this study, we present a multi-objective virtual machine (VM) placement scheme (considering VMs as fog tasks) for ECDCs called **TRACTOR**, which utilizes an artificial bee colony optimization algorithm for power and network-aware assignment of VMs onto PMs. The proposed scheme aims to minimize the network traffic of the interacting VMs and the power dissipation of the data center's switches and PMs. To evaluate the proposed VM placement solution, the Virtual Layer 2 (VL2) and three-tier network topologies are modeled and integrated into the CloudSim toolkit to justify the effectiveness of the proposed solution in mitigating the network traffic and power consumption of the ECDC. Results indicate that our proposed method is able to reduce power energy consumption by 3.5% while decreasing network traffic and power by 15% and 30%, respectively, without affecting other QoS parameters.

KEYWORDS
artificial bee colony, cloud computing, cloud data centers, network traffic, power consumption, VM placement

1 | INTRODUCTION

Cloud computing provides the ability for omnipresent, accessible, upon request network accessibility to a group of shared adjustable virtualized resources, which include network bandwidth, CPU, storage, and various other services. Such virtualized resources are able to be accessed rapidly and released with a minimum management endeavor or service provider communication.[1,2] Moreover, these resources are provided to customers as a service on the Internet-based on the pay-for-use pricing design.[3,4] This provisioning model allows cloud users to reduce operation and maintenance costs.[5,6]

Virtualization is considered as an indispensable specification of cloud computing and provides enhancements to location independence, resource pooling,[7] rapid elasticity, and security.[8,9] By allocating virtual machines (VMs) to physical machines (PMs), data center administrators are able to assign multiple tasks/users onto the same host for better data center resource utilization.[10,11] However, to be more effective, fog tasks should be placed on appropriate PMs using a process called VM placement (VMP)[12,13] shown in Figure 1. Proper placement of VMs is very important in the cloud environment to effectively improve the power effectiveness and resource utilization in the edge-cloud infrastructure.[14,15] However, inefficient VMP can increase the number of active PMs, which leads to more energy consumption and network traffic.[16,17] To prevent these problems, numerous researches have been conducted to find optimal VMP on data centers' PMs.[18,19]

In Masdari et al.,[3] we have studied VMP schemes and analyzed their properties, features, and limitations. Nowadays, due to the rising concerns of energy costs in the edge-cloud data center (ECDC)[20] and emerging bandwidth-intensive applications, power consumption and network traffic of VMs should be taken into account in the VMP operations.[21] Swarm intelligence algorithms can be used to design VMP policy, and it has been reported that the optimization algorithm of artificial bee colony (ABC) is the foremost optimization algorithm among all the others[22] to find an optimum solution for multi-objective optimization and NP-complete problem such as resource scheduling and resource allocation. There is a need for an effective technique for VMP while reducing network traffic and energy consumption simultaneously.[23] In this paper, a **TRA**ffic-aware and power effi**C**ient VM placemen**T** algorithm for edge-cl**O**ud data cente**R** called *TRACTOR* is proposed by using the ABC optimization algorithm to improve the effectiveness of the network traffic and power consumption. ABC algorithm is an optimization algorithm proposed for solving numerical problems.[22] This algorithm is on the basis of the intelligent behavior of the honeybee swarms and replicates their foraging behaviors.[24,25] The purpose of this research work has been the formulation of the VMP problem as a multi-objective optimization problem to lower the power consumption of the PMs and data center switches. Moreover, it considers the amount of data transfer between VMs and is aimed to decrease the network traffic between PMs by the assignment of the interacting VMs to the appropriate machines in an efficient manner. Extensive simulations in the CloudSim toolkit
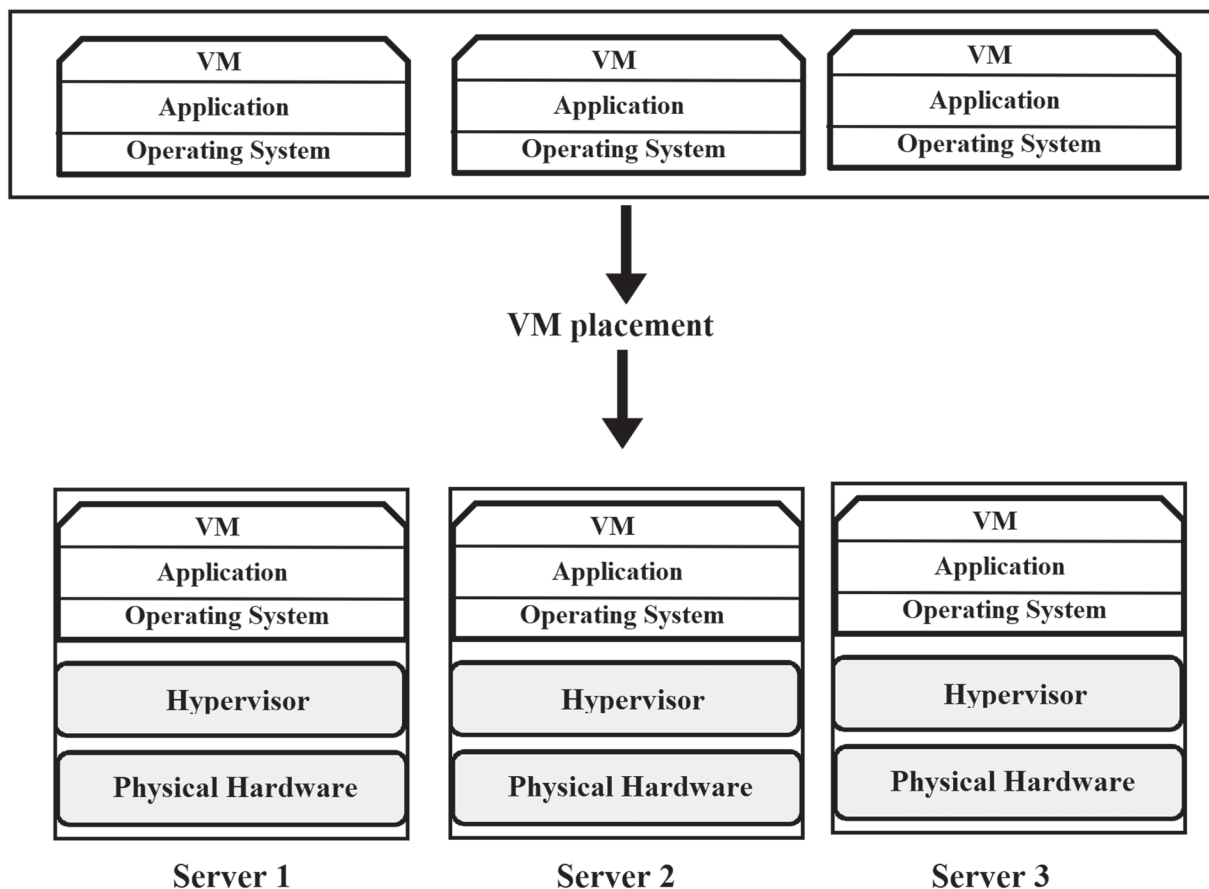

FIGURE 1 VM placement

indicate the effectiveness of our proposed solution in increasing the performance of the ECDC. The *main contributions* of the paper are mentioned as below:

- Modeling VMP as a multi-objective problem aimed to decrease the network traffic and power expenditure of the PMs and network switches.
- Presenting an ABC optimization algorithm-based VMP policy for ECDCs.
- Extensive simulation of the proposed VMP algorithm in the CloudSim toolkit based on the Virtual Layer 2 (VL2) and three-tiered network topologies.
- The performance of the proposed VMP solution and the CloudSim's VM allocation policy and the greedy VMP algorithms are compared.

The rest of the article is structured as follows: Section 2 displays a brief overview of the state-of-the-art VMP schemes presented for cloud computing. Section 3 briefly illustrates the algorithm of the ABC optimization, and Section 4 presents our proposed multi-objective VMP solution. Section 5 demonstrates the performance assessment and the results of the experiment. And at last, in Section 6, the concluding remarks and future research works are depicted.

2 | RELATED WORKS

In this section, a review of the existing research work in the area of VMP for ECDCs is presented. VMP in ECDCs is an NP-complete problem, and, in the literature, there is the presentation of numerous placement schemes.[3] This section is categorized into three groups based on their aims:

2.1 | Power and energy efficiency-based VMP policies

In their study,[26] Huang et al. provided an energy-efficient VMP solution on the basis of the model of multidimensional space partition. In this scheme, when a new VMP should be performed, the resource consumption for each feasible PM is checked and then the most appropriate PM is selected according to their proposed model. Thus, the data center resource is able to be utilized in an equitable way and creates smaller resource fragments, consuming less energy. In their study,[27] Ting et al. presented VMP and traffic configuration algorithm (VPTCA). In order to minimize the power consumption in the data center, they use the genetic algorithm (GA). As decisions are being made on VMP, VPTCA takes the three abovementioned factors and their relationship into account. VPTCA outperforms the first fit and elastic tree placement algorithms in the light traffic and heavy traffic load in the data center. Also, good network performance having a low average end-to-end delay, a low ratio of the dropped packets, and high transmission throughput can be achieved by VPTCA. In their work,[28] Piao and Yan presented a heuristic scheme called power-saving ABC (PSABC) that applies an improved ABC approach, binary search, and Boltzmann selection policy to provide a reduction of power. In the proposed PSABC algorithm, the Bayes theorem is used to converge rapidly to the optimal of the globe and making the performance of live VM migration better. In comparison with the random technique and other available optimization approaches, this scheme has lowered extra power consumption and breakdown events of the live VM migration to provide green ECDCs.

EAGLE is another energy-efficient online VMP scheme proposed in Li et al.,[29] which provides balanced resource utilization. A multidimensional space partition model is proposed with the aim of designing the resource-balanced placement. In comparison with the traditional greedy VMP algorithms, including the first-fit algorithm, placing each VM on any available PM, this algorithm creates fewer fragments of cloud resources and uses less energy. In their work,[30] Zhao et al. investigated the equilibrium between reducing PM power and securing VM performance and put a power-aware and performance-guaranteed VMP (PPVMP) forward. At first, they examine the relationship between the consumption power and CPU utilization to make a nonlinear power method, which is essential for the VMP. In this paper, a multiobjective plan for VMP is implemented, whose objective is to minimize PM power consumption and ensure VM performance. In their work,[31] Gharehpasha et al. have presented a new model of the ant colony scheme (ACS) so that energy usage in cloud data centers is lowered. To examine the efficiency of the proposed algorithm, various simulation-based experiments have been conducted on small, medium, and large scale data centers. They also

compared the results with two different ACS methods and the FFD algorithm. After comparing, it is proven that their new approach exhibits acceptable results.

2.2 | Network awareness-based VMP policies

Piao and Yan[28] presented a policy in which the VM is placed based on the network I/O and provide a VM migration and placement approach to handle the conditions where the network connection's condition reduces the application performance. In this scheme, the placement policy improves the data access by placing a VM on a PM where the data will be transferred faster. In the proposed scheme, VM migration is initialized when the period of the data transfer surpasses a certain threshold owing to the unstable network. Afterward, another improved machine is selected considering the present network status, and the VM is migrated to this PM for higher efficiency. In terms of the proposed VM allocation policy, the data can be accessed faster by the task, as the hosted VM is placed on the PM that utilizes a better network bandwidth. In their study,[32] Fang et al. proposed VM Planner, which handles a network-wide power that tries to improve the VMP and traffic flow routing. They consider the power consumption in VMP and traffic routing. VMP is designed as a combinatorial optimization problem and decomposes it into three separate classic NP-complete problems, including power-aware inter-VM traffic flow routing, traffic, and distance aware VM grouping to server-rack mapping.

2.3 | Multi-objective-based VMP policies

In Gao et al.,[12] the VMP is considered as a multi-objective optimization problem to cut the wastage of the resource and power usage. An adjusted version of the ant colony system algorithm is presented to be dealt with the big solution space in large ECDCs. They have made a comparison between the performance of their proposed approach and a multi-objective GA, two single-objective algorithms, and a bin-packing algorithm. In their work,[33] Chen et al. presented a VMP scheme to boost the data center's resource utilization and reduce the runtime reconfiguration costs. They applied the vector arithmetic for modeling multidimensional resource usage balancing and increasing resource utilization. After that, they provide a two-level runtime reconfiguration method to include local adjustment and VM parallel migration and satisfy the migration of VM and total migration time. In another work,[31] Gharehpasha et al. concentrated on how to solve the VMP problem regarding the existing bandwidth being formulated as a variable-sized bin packing problem. Also, a novel bandwidth allocation approach is engendered and combined with an optimized whale optimization algorithm variant, which is called an improved levy-based whale optimization algorithm. The results obtained were equivalent to many optimizations.

In previous study,[34] Satpathy et al. proposed a comprehensive model including a scheduling structure to arrange and queue a considerable set of VMs and crow search-based VMP, where a multi-objective VMP algorithm is used to utilize resource allocation and reduce power consumption at ECDCs. Further, three VM migration approaches, including serial, parallel, and improved serial as an inseparable part of the cloud computing environment, is considered. In Gupta and Amgoth,[7] a novel algorithm was proposed for the Infrastructure as a Service (IaaS) cloud to achieve two important objectives. The first objective of the proposed approach is minimizing power consumption in cloud data centers by reducing active PMs. The second objective concentrates on resource utilization, and the strategy that they conducted is able to find unbalanced VMs conveniently. They have proposed a multi-objective PSO algorithm in Luo et al.[35] It considers physical resource utilization and link failure rate as an optimization target; also, user requests are satisfied efficiently, and results illustrate that link failure and energy consumption are decreased notably.

In their work,[31] Gharehpasha et al. proposed a novel approach using a combination of the sine–cosine algorithm and swarm algorithm for VMP. In the proposed method, reducing power consumption and resource wastage is considered by reducing the number of active PMs. Tuli et al.[36] offered an A3C real-time scheduler for stochastic edge-cloud environments. Also, for capturing a vast number of host and task parameters together with temporal patterns, R2N2 architecture is used to give useful scheduling determinations. The conducted experiment on a real-world data set indicates a notable enhancement in energy expenditure, latency, and Service-Level-Agreement comparison with previous works. Azizi et al.[37] proposed a large-scale CDC with heterogeneous and multidimensional resources using a greedy randomized VMP (GRVMP) algorithm. The method is established on two characteristics, including placing VMs on more power-efficient PMs to reduce power consumption and resource utilization. The experiment results illustrate that the technique performs effectively in the mentioned metrics. A framework named FogBus that helps end-to-end

IoT-fog (edge)-cloud integration is proposed by Tuli et al.[38] The introduced model promotes IoT application deployment and resource utilization in comparison with existing frameworks and the influence of different FogBus adjustments on system efficiency. The results indicate that the FogBus is lightweight and responsive in comparison to fog and cloud infrastructures, and it can be modified based on situation requirements.

In their study,[39] Li et al. introduced a novel approach to minimize the consumption of energy in order to maximize resource utilization in VMP. There have been two algorithms used on the basis of chemical reaction optimization (CRO), that's to say CVP (CRO-VMP-permutation) and CVV (CRO-VMP-vector). The outcome results are compared with best fit decreasing (BFD), first fit decreasing (FFD), Cuckoo search optimization (CSO), and reordered grouping GA (RGGA). Consequently, it is proven that their approach can mostly perform better. In their work,[40] Mohammadhosseini et al. presented a VMP approach, namely, a balance-based cultural algorithm for VMP (BCAVMP) where a different fitness function was applied. This approach considers the balanced utilization of resources through the sum of the balance vector length and fitness function to reduce energy consumption. Outcome results prove that resource utilization and power consumption can be enhanced in cloud data centers. In Usman et al.,[41] an energy-oriented flower pollination algorithm (E-FPA) for VMP in cloud data centers was introduced by Yau Gital et al. with the purpose of decreasing data center energy consumption and enhancing resource utilization of the available physical resources.

Table 1 presents a comparison of the proposed VMP investigations. As it is depicted in the Table 1, there are few schemes which take both traffic of the network and power consumption in the VMP into account. Also, few power-aware placement schemes even consider the network switches and their links to power consumption. Our adjustable multi-objective approach considers the power consumption of servers and network elements and the network traffic. It is feasible to consider each goal separately or consider a balance between them. Moreover, the type of applied algorithm, mostly bio inspirational and metaheuristic algorithms, is specified in each investigation. Among these schemes, it can be seen that our proposed approach is implemented in the edge computing environment while the other research works are studied in the cloud computing environment.

TABLE 1 Comparison of the existing techniques with proposed scheme (TRACTOR)

Scheme	Traffic-aware	Energy-aware	Algorithm type	Multi-objective optimization problem	Cloud computing	Edge computing
[12]		✓	Ant colony optimization	No	✓	
[26]		✓	Heuristic technique	No	✓	
[27]		✓	Genetic algorithm	No	✓	
[18]		✓	Heuristic technique	No	✓	
[28]	✓		Banker algorithm	No	✓	
[32]	✓	✓	Heuristic technique	Yes	✓	
[22]		✓	Artificial bee colony	No	✓	
[33]		✓	Heuristic	No	✓	
[42]		✓	Ant colony optimization	No	✓	
[43]	✓	✓	Memetic algorithm	Yes	✓	
[44]		✓	Learning automata	No	✓	
TRACTOR (this work)	✓	✓	**Artificial bee colony**	**Yes**	✓	✓

3 | ABC ALGORITHM

Karaboga and Akay[45] compared the performance of the ABC algorithm with other bio-inspired algorithms such as GA, particle swarm optimization (PSO), and DE using 50 different functions. The outcome of this study indicates that the ABC algorithm performs better in more than half of these scenarios. The proposed algorithm is adjusted to enable a traffic-aware and power-efficient approach to heterogeneous VMs on PMs. The framework determines an optimal solution that also establishes equilibrium between the global search exploration and the local search exploitation. Resource constraints, including processor, storage, and memory of PMs, are considered in this framework.

We used the ABC algorithm for VMP in the following steps: (1) We define a certain number of scout bees to search the environment; each bee proposes a solution by an array with the size of the number of VMs, which is indicated in Figure 2.

Solution = $[V_1 \, V_2 \, ... \, V_n]$ where V_i is between the minimum and the maximum index of PM.

For instance, solution [a x f g h], represents the VM(3), will be placed on the host (f).

This is the way of representing a placement solution in the algorithm, which should be checked for constraints of PMs' resources. Afterward, the cost of the proposed solution is calculated by a function that we will explain in the following sections, a solution with lower cost is chosen as better one, solutions with a high rate of cost are rejected and replaced by new random ones.

The function is based on two-part power and traffic, as discussed below:

The ABC algorithm[46] applies three sorts of bees named employed bees, scouts bees, and onlookers. Onlooker is a bee that stands by the dance area to determine choosing a food source, and the one which goes to the food source visited before being named is an employed bee. The scout bees search randomly to discover new sources. Each food position indicates a solution which is possible to the problem, and the value of food source nectar specifies the fitness value or quality of the solution, which can be computed using Equation 1:

$$Fit_i = \frac{1}{1+f_i} \tag{1}$$

In the ABC algorithm, the food position indicates a feasible solution, and at first, a fortuitously allotted initial population is created. Also, employed or onlooker bees must be initialized corresponding to the solutions in the mentioned population. In this algorithm, only one employed bee uses each food source, and the fitness of the solution specifies the amount of nectar in a food source. The food resource is selected by an onlooker bee based on the calculated probability value P related to the food source that is possible to be determined as indicated in Equation 2:

$$P_i = \frac{Fit_i}{\sum_{n=1}^{SN} Fit_n} \tag{2}$$

In this equation, Fit_i is the calculated fitness value of the ith solution, and the food source number is specified by SN, which needs to be equal to the number of the onlooker or employed bees.[47] The first positions of the food sources are fortuitously made in which each employed bee is designated to a random food source. Afterward, each of the employed bees, using Equation 3, determines a novel neighboring food source and calculates the amount of the nectar of the novel food source for each of them. If the new food source fitness value is greater than the old one, then the employed bee will start moving to the new food source, or else it will use the previous one.

$$V_{ij} = x_{ij} + \emptyset_{ij} \left(x_{ij} - x_{kj} \right) \tag{3}$$

VM(1)	VM(2)	VM(3)	VM(4)	VM(5)	...	VM(n)
a	b	c	d	e	....	z

FIGURE 2 Solution representation

In Equation 3, $\emptyset$ stands for an accidental number between [−1] and [1], v_i is a candidate solution, x_i for the existing solution and x_k for a neighbor solution, and $j \in \{1, 2, ..., D\}z$ is an accidentally chosen index where D stands for the dimension of the solution vector. In this algorithm, when a position cannot be optimized after the specified number of repetitions, the food source needs to be regarded as discarded, and the employed bee of the same food source gets a scout. Then, in that position, the scout bee, using Equation 4, produces a new solution randomly:

$$x^j_i = x^j_{min} + rand(0,1)\left(X_{max} - x^j_{min}\right)$$

(4)

where x^j_i is the new position of the scout bee (i) and x^j_{min} and X_{max} are the minimum and maximum values for the dimension (j), respectively. V is produced after each candidate source position; then, the artificial bee evaluates it, and its fitness is compared with that of its old one. The new food source substitutes the old one in the memory when it provides equal or better nectar. If not, the old one will be retained in the memory. To put it differently, a voracious selection technique is applied as the selection operation between the former and the nominated one.[48] Figure 3 indicates the ABC pseudocode.

4 | LEVY FLIGHT

Levy flight is an accidental model of walk that expresses the anomalous nature diffusion.[49] The Levy distribution is satisfied by its distribution, which has long-tail characteristics. Since similar methods of Levy flight are used by the flying insects in nature, such as bees and fruit flies, they have inspired several scholars to bring in Levy flight in the design of evolution to optimize the achievement of the algorithm to reach good results. As the specific method is located in the bees' collecting phase of the ABC algorithm, there will be two parts of SN; one part will have the job of collecting the region's optimal information based on the original algorithm, and the other one does Levy flight near the existing best global solution to optimize the capabilities of the global search. And here is its adapted equation as below:

$$x'_{ij} = x_{ij} + c_1 \frac{\varphi u}{|V|^{1/\beta}}\left(x_{ij} - x_{best}\right)$$

(5)

where c_1 stands for the step adjustment factor and normally is considered to be as 0.01; u, V are random numbers meeting usual standard distribution; θ is a constant satisfying $0 < \theta < 2$; $\varphi = \left[\frac{\Gamma(1+\theta)\sin(\pi\theta/2)}{\Gamma\left(\frac{1+\theta}{2}\theta.2^{(\theta-1)}2\right)}\right]^{1/\theta}$; Γ is the standard gamma function.

Algorithm 1: Artificial Bee Colony	
1:	Begin
2:	Initial Pop()
3:	While remain iterations do
4:	Site selection for local search
5:	assign bees for the selected sites
6:	and to compute fitness
7:	find the bee with the best fitness
8:	Allocate the remaining bees to look
9:	for randomly
10:	compute remaining bees fitness
11:	Update Optimum Solution()
12:	End While
13:	Return BestSolution
14:	End

FIGURE 3 The pseudocode of ABC algorithm

5 | PROPOSED VMP SOLUTION

This section presents the proposed multi-objective VMP approach designed to lower the power consumption of cloud data centers. This scheme is aimed to reduce the energy consumption of the PMs and the network switches by decreasing the number of active switches and active links required for the VMs' interactions. An ABC-based VMP algorithm to achieve the mentioned objectives is offered in the present section. In the proposed ABC-based VMP approach, a cost function is needed to compute the fitness value of each solution and make decisions about the solutions. To achieve the objectives of the proposed solution, this cost function should consist of three parts, which are PMs' power consumption, network switches power consumption, and network traffic, as discussed below. This cost function is indicated in Equation 6:

$$F = \alpha F_1 + \beta F_2 + \pi F_3 \tag{6}$$

In this equation, α, β, and π are the coefficients that are used to tune the impact of each objective in the fitness value. Also, F_1 is the PMs' total power consumption in the data center, and F_2 is the total network cost, which depicts the data transfer cost between PMs. Moreover, F_3 specifies the total power consumption of the switches of the network.

5.1 | Power consumption

In the VMP scheme, which has been put forward, the total electricity consumption of the PMs can be completed using Equation 7:

$$F_1 = \sum_{i=1}^{n} p_i \tag{7}$$

where F_1 is the total amount of the PMs' power consumption, P_i is the power consumption of the ith PM, and n is the number of the PMs of the data centers. Recent studies indicate a linear relationship existing between the PM's power consumption and utilization of its CPU.[12] By using this, the power consumption of each PM will be possible to be computed, as indicated in Equation 8:

$$P_i \begin{cases} \left(P_i^{max} - P_i^{idle}\right) * U_i^c + P_i^{idle} & U_c^i > 0 \\ 0 & otherwise \end{cases} \tag{8}$$

In this equation, the maximum power consumption of the ith PM is P_i^{max}; in its full utilization, P_i^{idle} is the power consumption of the ith PM in idle mode, and U_i^c is the CPU utilization of the ith PM. It is worth noting that the CPU rate in the sleep mode is about half of the maximum rate. But, by placing some VMs on a PM, its CPU rate increases based on the VMs' CPU requests. The utilization of each PM can be calculated using Equation 9:

$$Uic = \frac{\sum_{j=0}^{m}(xj * Rj)}{Ai} \tag{9}$$

In this equation, m is the number of VMs placed on the PM_i, A_i is the available CPU for PM_i, R_j is the requested CPU of the VM_j and x_j is a binary value which can be computed by Equation 10:

$$X_j = \begin{cases} if\ VMj\ is\ placed\ on\ the\ PMi & 1 \\ if\ VMj\ is\ not\ placed\ on\ the\ PMi & 0 \end{cases} \tag{10}$$

5.2 | Network traffic

Because VMs may execute interacting applications such as workflows, they often need to interact with each other. As indicated in Figure 4, the amount of data transmission between VMs can be specified by an upper triangular matrix. In this matrix, D_{ij} indicates the amount of the data which should be transferred between the VM_i and VM_j. In Figure 4, the sum of all elements in the matrix represents the total amount of the data that are needed to be exchanged between all VMs. Moreover, in this scheme, another upper triangular matrix is defined to indicate the link capacity between different PMs. The speed of data transfer between VMs depends on the available bandwidth between the PMs, which depends on the applied network topology and switches.

Figure 5 indicates the available bandwidth between the PMs. In this matrix, C_{ij} is the link capacity between the ith PM (PM_i) and jth PM (PM_j) in megabit per second.

After VMs are placed on the PMs, they may interact with each other. The matrix X indicated in Figure 6 shows the amount of the data that must be transferred between the PMs because of their VMs interactions.

In this matrix, X_{ij} indicates the amount of the data that will be transferred between the ith PM (PM_i) and jth PM (PMj) in megabit per second. After a solution is found for VMP, the total network cost can be calculated by Equation 11:

D_{ij}	VM_0	VM_1	VM_2	VM_3	VM_4
VM_0	0	D_{01}	D_{02}	D_{03}	D_{04}
VM_1	0	0	D_{12}	D_{13}	D_{14}
VM_2	0	0	0	D_{23}	D_{24}
VM_3	0	0	0	0	D_{34}
VM_4	0	0	0	0	0

FIGURE 4 Required data transmission between VMs

C_{ij}	PM_0	PM_1	PM_2	PM_3	PM_4
PM_0	0	C_{01}	C_{02}	C_{03}	C_{04}
PM_1	0	0	C_{12}	C_{13}	C_{14}
PM_2	0	0	0	C_{23}	C_{24}
PM_3	0	0	0	0	C_{34}
PM_4	0	0	0	0	0

FIGURE 5 Link capacity between PMs

X_{ij}	PM_0	PM_1	PM_2	PM_3	PM_4
PM_0	0	X_{01}	X_{02}	X_{03}	X_{04}
PM_1	0	0	X_{12}	X_{13}	X_{14}
PM_2	0	0	0	X_{23}	X_{24}
PM_3	0	0	0	0	X_{34}
PM_4	0	0	0	0	0

FIGURE 6 Required data transfer between the PMs

$$F_2 = \sum_{i=0}^{n-1} \sum_{j=i+1}^{n-1} Cost_{ij} \tag{11}$$

In this equation, $F2$ is the total network traffic cost, and n shows the number of PMs in the data center. Also, $Cost_{ij}$ indicates the cost of the data transfer between the PM_i and PM_j that can be computed by Equation 12:

As outlined before, x_{ij} is the amount of the data transfer between the PM_i and PM_j, and C_{ij} is the link capacity between them.

$$Cost_{ij} = \begin{cases} \dfrac{X_{ij}}{C_{ij}} & i \neq j \\ 0 & i = j \end{cases} \tag{12}$$

5.3 | Network power consumption

The third objective of the proposed VMP scheme is the mitigation of the power consumption of the network switches. In this VMP scheme, the total amount of the power consumption of the network switches or F_3 can be computed by Equation 13:

$$F_3 = \sum_{i}^{ns} Ps_i * Bs_i + \sum_{j}^{nl} pl_j * Bl_j \tag{13}$$

In this equation, ns indicates the number of switches.

In the network, Psi indicates the power consumption of the ith switch, and Bsi is a binary value, which indicates that the ith switch is on or off. Also, nl indicates the total number of links in the switches, and plj is a binary value, which indicates that the jth link is active or not. Thus, when the jth switch is in use, plj is 1; otherwise, it is zero. Because, for each activated switch link, more power is applied, the second part of this equation checks all of the activated links in topology.

5.4 | Pseudocode of the proposed algorithm

In this solution, a certain number of employed bees are applied to achieve an optimal solution. Also, the number of employed bees is considered to be the host number, and onlooker bee number can be calculated by Equation 14:

$$N_{onlooker} = N_{employed*} P_i + 1 \tag{14}$$

In this equation, each onlooker bee represents a solution where indicates the placement of each VM on a PM. Equation 15 provides a more elaborate version of Equation 6 in which F_1, F_2, and F_3 parameters are replaced by Equations 7, 11, and 13, respectively. Also, Equation 16 indicates a more elaborate version of Equation 1, where the F parameter is

$$F = \alpha \left(\sum_{i=1}^{n} pi \right) + \beta \left(\sum_{i=0}^{n-1} \sum_{j=i+1}^{n-1} Cost_{ij} \right) + \pi \left(\sum_{i}^{ns} Ps_i * Bs_i + \sum_{j}^{nl} pl_j * Bl_j \right) \tag{15}$$

$$Fitness = \frac{1}{1 + \alpha \left(\sum_{i=1}^{n} pi \right) + \beta \left(\sum_{i=0}^{n-1} \sum_{j=i+1}^{n-1} Cost_{ij} \right) + \pi \left(\sum_{i}^{ns} Ps_i * Bs_i + \sum_{j}^{nl} pl_j * Bl_j \right)} \tag{16}$$

$$P = \frac{\alpha \left(\sum_{i=1}^{n} pi\right) + \beta \left(\sum_{i=0}^{n-1}\sum_{j=i+1}^{n-1} Cost_{ij}\right) + \pi \left(\sum_{i}^{ns} Ps_i * Bs_i + \sum_{j}^{nl} pl_j * Bl_j\right)}{1 + \sum_{n=1}^{SN} \alpha \left(\sum_{i=1}^{n} pi\right) + \beta \left(\sum_{i=0}^{n-1}\sum_{j=i+1}^{n-1} Cost_{ij}\right) + \pi \left(\sum_{i}^{ns} Ps_i * Bs_i + \sum_{j}^{nl} pl_j * Bl_j\right)}$$

replaced by Equation 15. On the other hand, Equations 15 and 16 can better indicate which parameters are considered in our scheme for VMP. Also, the probability value for each solution can be calculated by Equation 17. Generally, there is a direct relation between the fitness value and this probability value. The result of this equation for each solution is compared with a random value between this [0,1]. If the probability value is larger, then a solution is chosen in that iteration.

Figure 7 provides the pseudocode of the proposed multi-objective ABC algorithm. This algorithm works as follows: In the first loop (Line 2), the ABC parameters and list of the PMs and VMs are initialized. Then for each bee, a new solution is produced, and the cost and the fitness are calculated by Equations 15 and 16. In the second loop, the probability value for each employed bee is calculated by Equation 17, and based on this value, the proposed algorithm makes a decision about employed bees to search their neighborhood or abandon them. This algorithm generates a random

```
       Algorithm 2: Artificial Bee Colony-based VM Placement
       Input: Load VM-list, Host-list,VMrelatiom [][],SN= hostlist.size, Max-iteration
       Output :Best[]//a proposed solution
       Generate initial population  employed bee =1....SN
1:     For   i=1 to SN
2:         Do
3:      Generate randomly solution for   employed bee [i]
4:            While(solution is safe for   employed bee [i])
5:            Calculate cost for  employed bee [i] from equation (16)
6:      Evaluate fit_i for   employed bee [i]from equation (17)
7:      End For
8:      For j=1 to Max-iteration
9:          For    k=1 to SN
10:            Rand=new random()//generate a random value betweem 0 and 1
11:            calculate the probability value p_j for the solutions in this iteration from equation(2)
12:     If ( p_j >Rand)//onlooker bee phase
13:                 Onlooker_number=[fit_i*SN]+1
14:               Onlooker bee[]=new bee[Onlooker_number]
15:                 For l=1 to Onlooker_number {
16:                 Produce new solution from  employed bee [k] using levyflight for each onlooker bee
17:             Do
18:               Generate randomly solution for   employed bee [i]
19:             While(the solution is safe for   employed bee [i])
20:                   If (cost onlookerbee<cost  employed bee )
21:                     employed bee =onlooker bee
22:                   Calculate the value f_i
23:               End If
24:           End For
25:           Else If( p_j <Rand)//scout bee phase
26:                   Bee scout bee;
27:                   Generate randomly solution for  scout bee
28:             Do
29:                   Generate randomly solution for scout bee
30:               While(the solution is safe for  scout bee )
31:                   Calculate cost for  scout bee from equation (15)
32:               Evaluate fit_i for  scout bee from equation (16)
33:               employed bee [i]=scout bee;
34:           End If
35:         End For
36:     BestsoFar[j]=FindLowestCost( employed bee [])
37:     End For
38:     Best=FindLowestCost(Bestsofar[])
```

FIGURE 7   Pseudocode of the artificial bee colony-based VM placement solution

value each time and compares it with the probability values. When for each employed bee, the probability value is less than the random value, the solution will be changed completely and replaced with the new one by scout bee, and if it is more than the random value, onlooker bees will be specified based on Line 13. The neighborhood of the accepted bees will be searched by the onlooker bees to do this. Each onlooker bee changes the place of some VMs randomly and calculates the cost and fitness. If the cost of the onlooker bee is less than the cost of the employed bee, the algorithm will replace the old, employed bee with the new onlooker bee. The best answer of each iteration will be saved in the last lines, and after finishing the second loop, this algorithm will search all the best answers of each step of the second loop to choose the best answer, which has the lowest cost. Table 2 indicates the variables applied in Equations 15–17.

6 | PERFORMANCE EVALUATION

To evaluate the proposed VMP scheme, extensive simulations are conducted in the CloudSim toolkit, which is an extendable simulation framework to enable simulation and modeling of the cloud computing infrastructures and services. CloudSim toolkit offers features to support simulating the framework of large scale cloud computing, which includes the data centers on a single physical computing node and a self-contained platform for modeling the data centers, scheduling, allocations policies, and service brokers. Moreover, CloudSim provides a virtualization engine for managing multiple, co-hosted virtualized services and flexibility to change between space- and time-shared processing cores allocation to the services virtualized.[50]

In our solution, the consumption of the network switches' power is considered in the placement decisions. For this purpose, it is necessary to consider some topology for the data center's network. As indicated in Figure 8, it is assumed that the data centers use three-tier or VL2[51] network topologies, and the switches' power consumption is computed in both cases. In our simulation, the number of elements in each topology is indicated in Table 3. In these scenarios, the power consumption of network components is considered as follows:

- 1-gigabit switch = 200 watts
- 10-gigabit switch = 30 watts
- 1-gigabit link = 6 watts

TABLE 2 Description of variables

Variable	Definition
α	Coefficient of f_1
β	Coefficient of f_2
π	Coefficient of f_3
pi	Power consumption of ith PM
n	Number of PMs
$Cost_{ij}$	The cost of transferred data between PM_i and PM_j
Ps_i	Power consumption of ith switch
Bs_i	Binary decision variable If $Bs_i = 0$ switch is disabled If $Bs_i = 1$ switch is enabled
l_j	Power consumption of ith link
Bl_j	Binary decision variable If $Bl_i = 0$ link is disabled If $Bl_i = 1$ link is enabled
ns	Total number of switches
nl	Total number of links
F	The cost function for each bee
$Fitness$	Fitness function for each bee
P	The calculated probability for each bee

FIGURE 8 Network topology

TABLE 3 Number of network elements

Topology	VL2	Three-tier
PM	16	16
1-gigabit switch	4	6
10-gigabit switch	8	12
1-gigabit link	16	16
10-gigabit link	16	32

- 10-gigabit link = 0.4 watts

This section presents the simulation results achieved by considering VL2 and three-tiered topologies for the data center's network. In these simulations, our proposed VMP solution and the CloudSim's simple VM allocation policy and the greedy VMP algorithms are compared with each other. In these comparisons, mainly of the following factors are evaluated in the simulation scenarios:

- PMs power consumption
- Network switches power consumption
- Number of the activated links in network switches
- Number of the activated switches in the data center network
- Percentage of CPU rate.

In all of these simulations, 16 PMs have been considered in the data center's network. Also, two kinds of PMs are used, eight of which have the following characteristics:

- CPU = 117 160 MIPS
- $P_{max} = 210$ watts and $P_{idle} = P_{max}/2$ watts

The specifications of the other eight PMs are as follows:

- CPU = 97 125 MIPS
- P_{max} = 129 watts and $P_{idle} = P_{max}/2$ watts

Moreover, each simulation is conducted for 16 VMs, 32 VMs, 48 VMs, and 64 VMs, and in each scenario, two types of VMs with the following characteristics are considered:

- CPU = 10 000 MIPS
- CPU = 8000 MIPS

Here, the second VM type corresponds to an edge device and the former as a cloud node. Figures 9 and 10 present the comparison of PMs' power consumption (watt) in the center of the data. As outlined before, the power consumption of each PM directly depends on its CPU load, and this load increases when more VMs are applied in the network. Thus, as shown in these figures, the power that the PMs consume goes up as the number of VMs goes up. As indicated in these figures, based on the different values for coefficients of the cost function, the proposed scheme can effectively mitigate the power consumption of the PMs during the time of the simulation. In our approach, the server power consumption is reduced by 3.5%.

Figures 11 and 12 indicate the percentage of the CPU rate in the PMs after all VMs are placed on them. As indicated in these figures, with the increase of VMs number, the percentage of CPU rate in the PMs increases. In these figures, the proposed solution is simulated with four different sets of values for coefficients of the cost function. The results of all these executions indicate that the proposed VMP solution is better than the other two VMP methods.
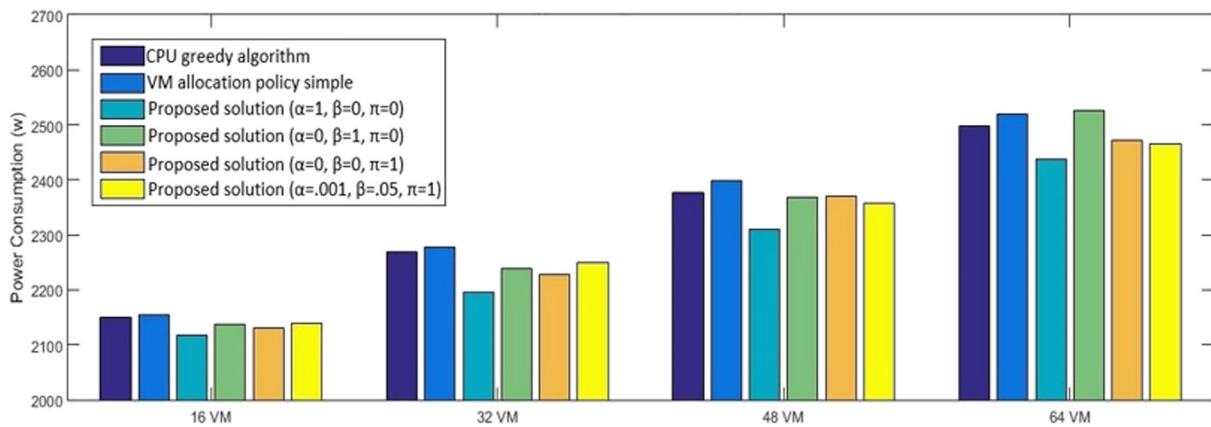
FIGURE 9 Comparison of the physical machines power consumption (W) in VL2 topology
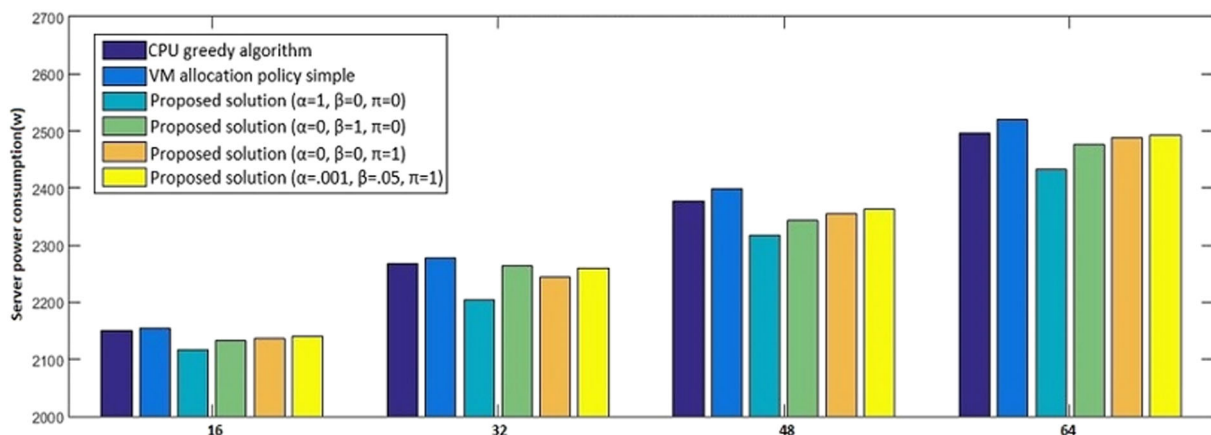
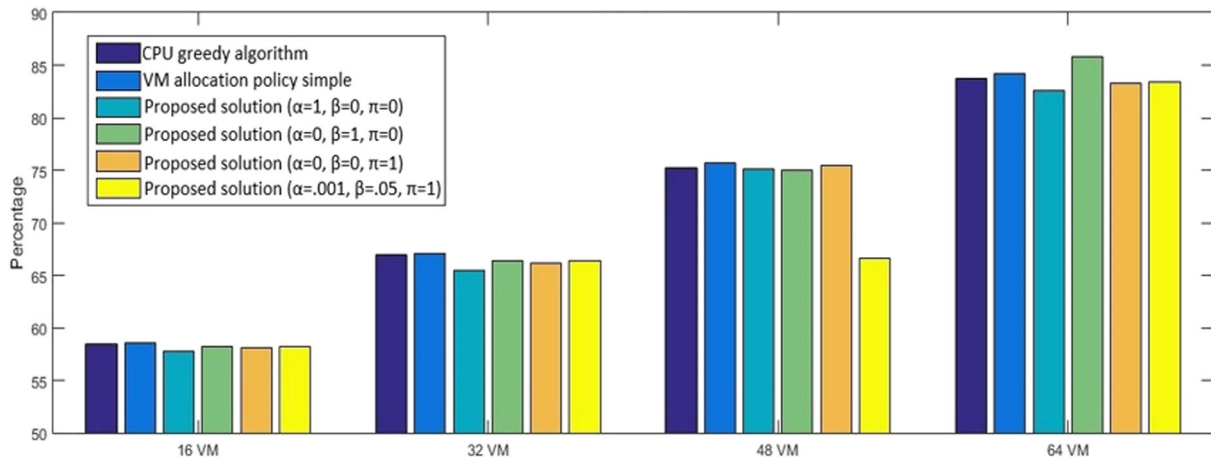**FIGURE 10** Comparison of the physical machines power consumption (watt) in three-tier topology

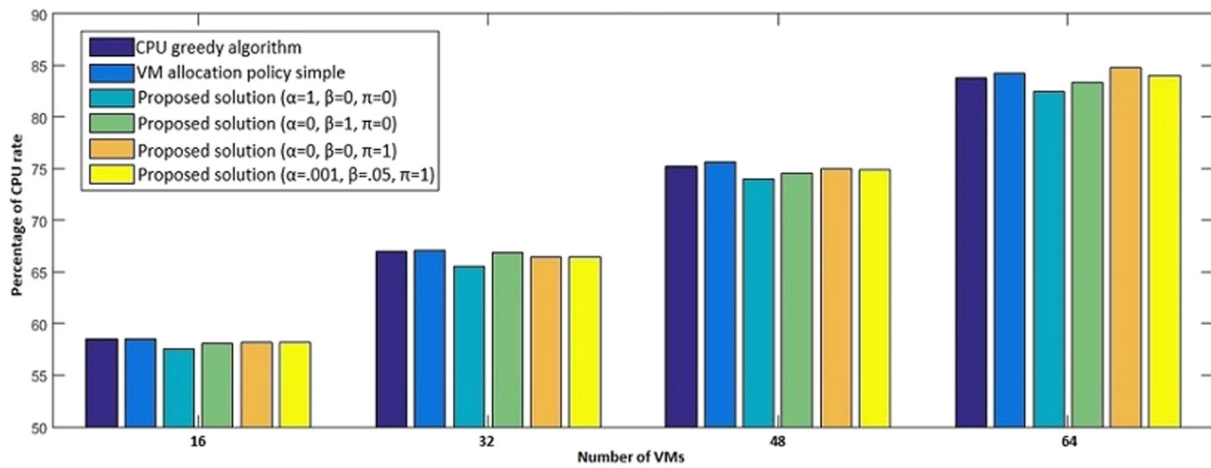**FIGURE 11** Comparison of the average of the maximum CPU rate in VL2 topology

FIGURE 12 Comparison of the average CPU rate in the three-tier topology
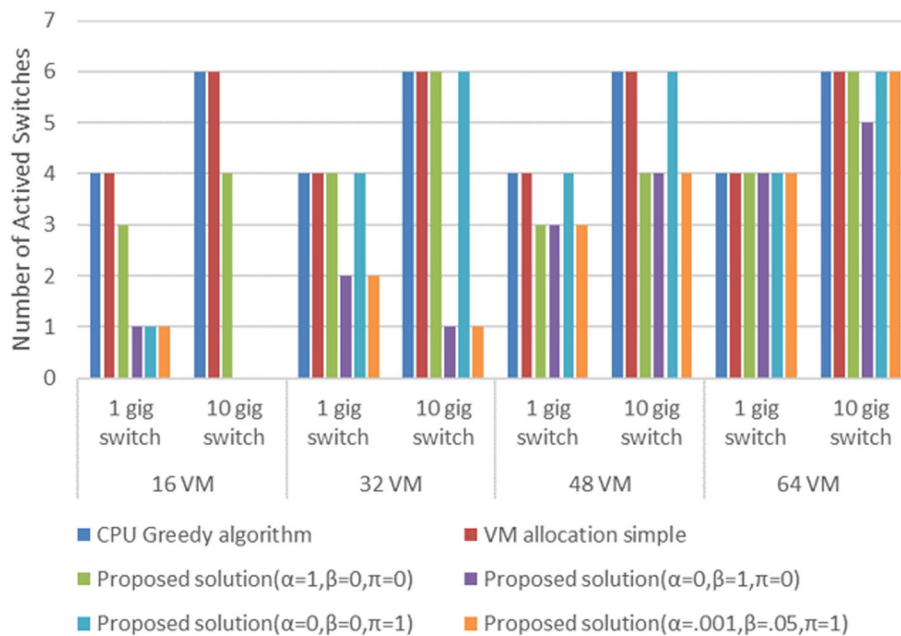

FIGURE 13 Number of the activated switches in the VL2 topology

The number of activated 1- and 10-gigabit switches in each scenario for the evaluated algorithms is shown in Figures 13 and 14. To be noted, the number of activated switches depends on the amount of the data transferred between PMs and the VMP algorithm, not the number of the applied VMs. In these figures, the proposed solution results of the simulation are indicated in four different cases where different values are applied for the cost function coefficients. As shown in these figures, in most scenarios, the proposed ABC-based VMP algorithm presents better results than the other two VMP methods.

Figures 15 and 16 indicate the number of the activated links in the 1- and 10-gigabit network switches applied in four cases with different numbers of VMs. It can be concluded from these figures that as the number of VMs and their transmitted data increases, the number of active links in the network switches increases accordingly. As shown in these figures, our scheme can greatly reduce the number of active links better than the other two schemes.

Figures 17 and 18 present the comparison of the consumption of the power of the network components in the four cases where different numbers of the VMs are placed on the 16 PMs. Again, the same as the previous simulation results, the results of the proposed solution are provided in four different cases where different values are applied for the coefficients of the cost function. As outlined before, these coefficients tune the effect of the network traffic and power consumption of the PMs and network switches. As indicated in this figure, except in the last scenario, our proposed solution consumes multiple times less power for all network switches. These simulations are conducted in four cases
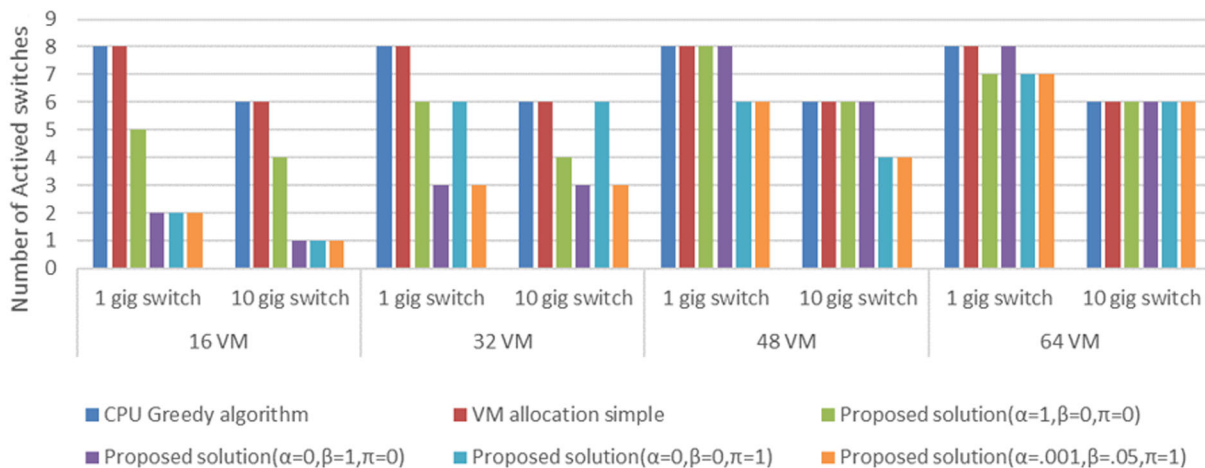

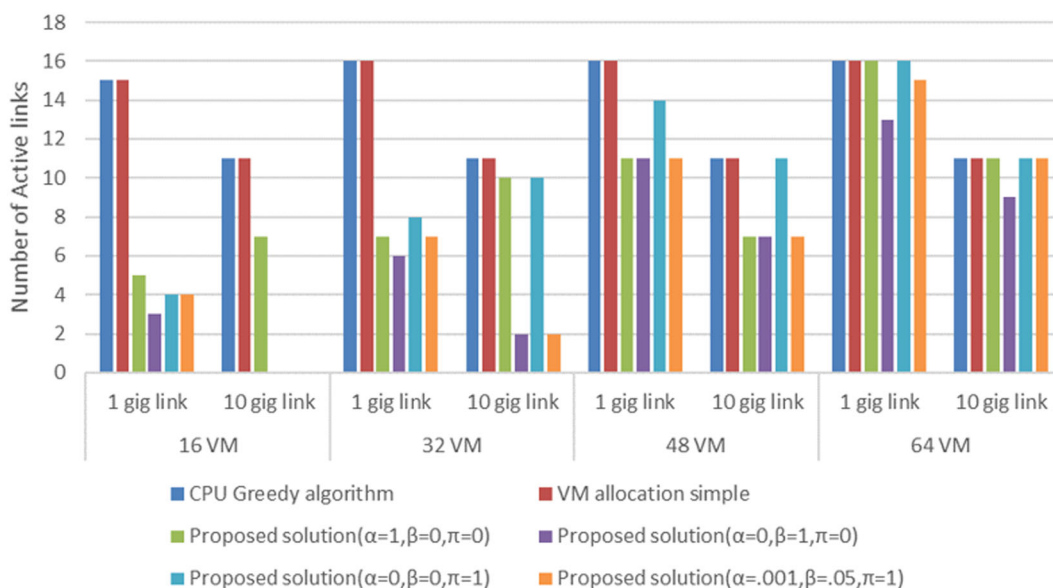**FIGURE 14** Number of the activated switches in the three-tier topology

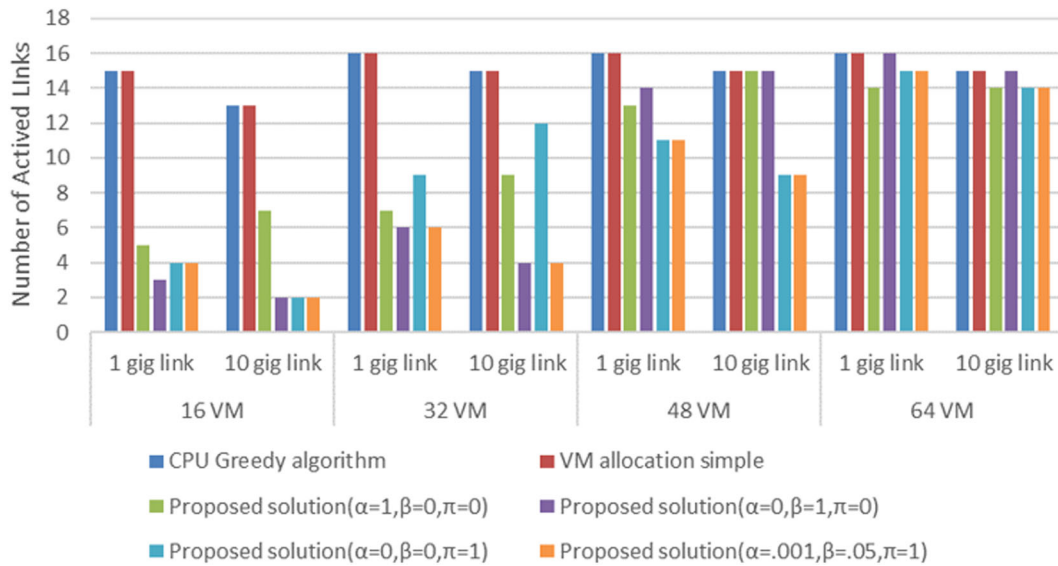**FIGURE 15** Number of the active links in the VL2 topology

FIGURE 16   Number of the active links in the three-tier topology
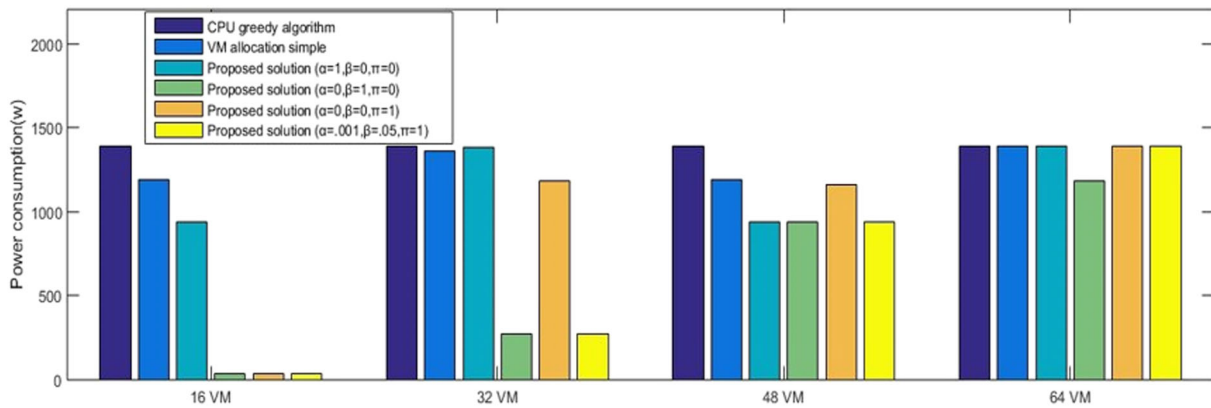

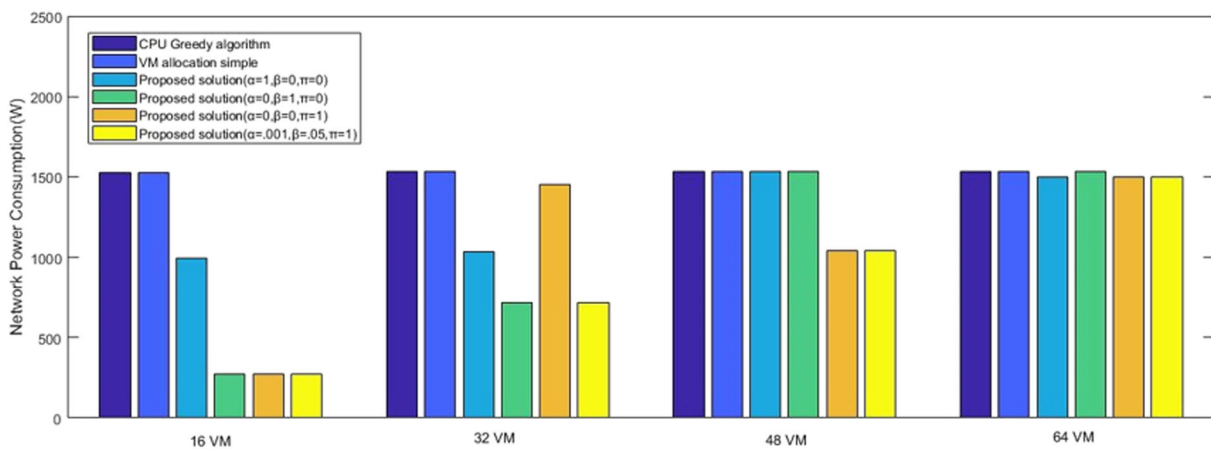**FIGURE 17**   Network power consumption (watt) in the VL2 topology

FIGURE 18   Network power consumption (watt) in the three-tier topology

where 16 VMs, 32 VMs, 48 VMs, and 64 VMs are considered for placement on the 16 PMs in the ECDC. The amount of energy consumption of the network has a direct relation to the number of VMs. For 16 and 32 VMs in both Figures 17 and 18, the energy consumption is reduced by nearly 70%. In the case of 48 VMs, our proposed approach consumes 20%
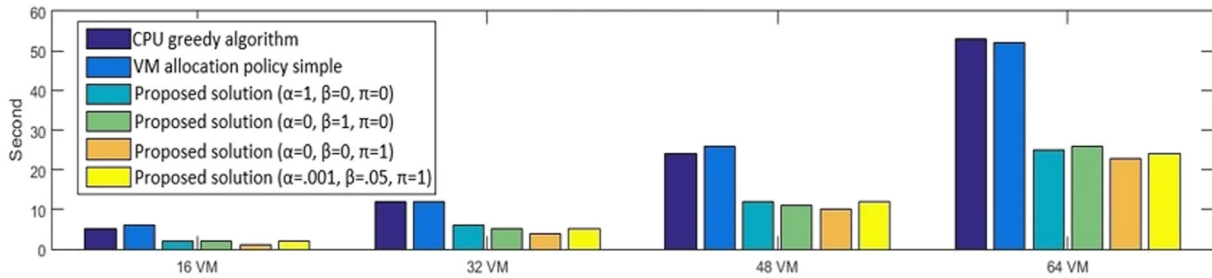
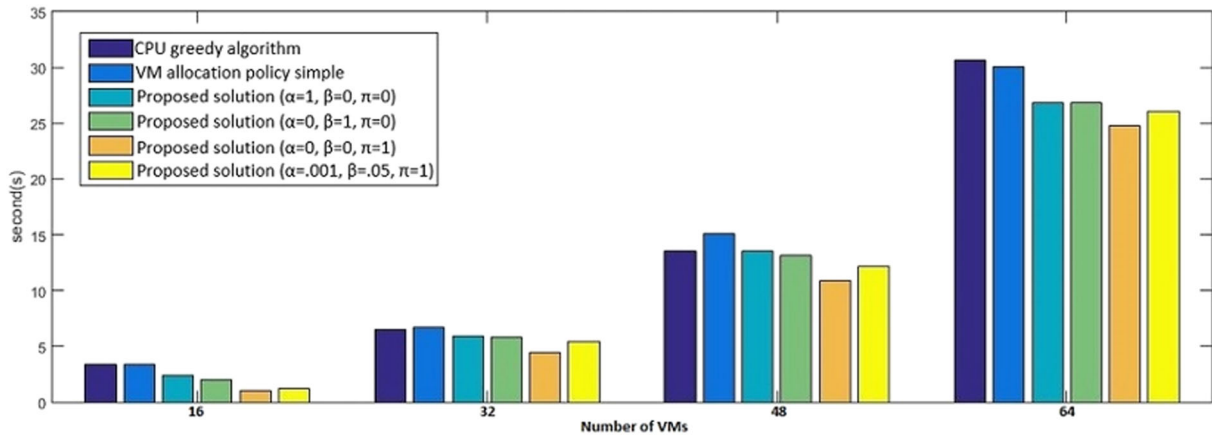**FIGURE 19** Network switches usage in the VL2 topology

FIGURE 20 Network switches usage in the three-tier topology

less energy compared to VM allocation simple and CPU greedy algorithm. In the last scenario, since the number of VMs is high, most of the network elements are active, and the results for all approaches are approximately the same.

Figures 19 and 20 indicate the total time period when network switches are activated in each scenario. As outlined in the previous sections, network switches provide a means for the required interactions between VMs placed on different PMs. Again, the results of these simulations are shown for 16 VMs, 32 VMs, 48 VMs, and 64 VMs, and our solution, in most cases, provides better results and applies network switches for less time. In the case of 16 VMs, the total activation time of network elements, our approach reduced by 4 and 2 s in comparison with CPU greedy and VM allocation simple for VL2 and three-tier, respectively. This rate in 32 and 48 consumes 50% less time in our solution. Finally, for 64 VMs, our approach saves more than 20 s.

7 | CONCLUSIONS AND FUTURE SCOPE

Cloud data centers consist of various power-consuming devices such as PMs and network switches. But, the high power consumption of these devices increases the data centers' maintenance costs and also may cause serious problems because of the excessive heat. Thus, reducing the power consumption of the ECDCs is of high importance in green cloud computing. To solve these problems, this study offers an ABC-based VMP scheme for cloud computing data centers called TRACTOR, which tries to lower the consumption of the power of the various data center's elements such as PMs and network switches. In addition, this VMP solution considers the network traffic between VMs and tries to reduce the network traffic by placing interacting VMs close to each other efficiently. This reduces the power consumption of switches and their links and increases the throughput of the data centers. Finally, the proposed ABC-based VMP solution is compared with the greedy VMP and VMP simple algorithms in the three-tier and VL2 network topologies. Experimental results indicate that TRACTOR is able to reduce power energy consumption by 3.5% while decreasing network traffic and power by 15% and 30%, respectively, without affecting other QoS parameters. The simulation results

indicate the effectiveness of our scheme in mitigating the consumption of the PMs' power, network switches, and the time period when switches are activated in both network topologies.

7.1 | Future research directions

Although the proposed approach is a comprehensive VMP and concerns different objectives, it can be enhanced in a larger scope under the following aspects:

1. *Thermal-aware management:* In the future, the TRACTOR can be extended by incorporating temperature as an optimization parameter along with energy consumption,[52] which further helps the temperature of the ECDC to be maintained.
2. *Security:* Considering the ever-increasing security attacks such as a sprawling attack, economic denial of sustainability (EDoS) attacks, and various other DoS attacks on virtualization, in future researches and studies, we will take into account the security issues in conducting VMP. Security of the data can be optimized using blockchain-based framework called FogBus.[38] This technology ensures the reliability of the systems. In the future, this technology can be applied for handling data in edge computing.
3. *Container-based deployment:* In the future, virtualization technology, which is used in our approach, can be substituted with containers. Container is a lightweight technology that is used to virtualize applications.[53] Using containers can enhance CPU performance and improve energy consumption.
4. *Internet of Things (IoT):* IoT is the network of objects, devices, buildings, and other cases, including electronic sensors and network connectivity, and this brings the ability to gather and interchanging data between objects. Since IoT and technology applications are developing, cloud and edge would be an effective infrastructure to manage data effectively.[53] Cloud computing can fill the gap of IoT, such as limited storage and applications over the Internet. Also, the main problem of cloud computing, limited scope can be solved through IoT.
5. *Artificial intelligence (AI):* AI can be used to make fog nodes aware of the workload environment and continuously adapt to provide better QoS. In addition, it reduces power consumption and total infrastructure cost. This method provides optimum VMP and migration effectively.[54]
6. *Serverless edge computing:* Further, TRACTOR can be implemented using serverless computing or function as a service (FaaS) to improve salability and reduce cost because there is no need of server configuration while deploying an application.[55] With the help of serverless computing, application can be easy to scale.

DATA AVAILABILITY STATEMENT
A significant amount of data is presented in this article. The remaining data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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