OP-MLB: An Online VM Prediction-Based Multi-Objective Load Balancing Framework for Resource Management at Cloud Data Center

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Abstract—The elasticity of cloud resources allows cloud clients to expand and shrink their demand for resources dynamically over time. However, fluctuations in the resource demands and pre-defined size of virtual machines (VMs) lead to lack of resource utilization, load imbalance, and excessive power consumption. To address these issues and to improve the performance of data center, an efficient resource management framework is proposed, which anticipates resource utilization of the servers and balances the load accordingly. It facilitates power saving, by minimizing the number of active servers, VM migrations, and maximizing the resource utilization. An online resource prediction system, is developed and deployed at each VM to minimize the risk of Service Level Agreement (SLA) violations and performance degradation due to under/overloaded servers. In addition, multi-objective VM placement and migration algorithms are proposed to reduce the network traffic and power consumption within data center. The proposed framework is evaluated by executing experiments on three real world workload datasets namely, Google Cluster dataset, Planet Lab, and Bitbrains VM traces. The comparison of proposed framework with the state-of-the-art approaches reveals its superiority in terms of different performance metrics. The improvement in power saving achieved by OP-MLB framework is up to 85.3 percent over the Best-Fit approach.

1 INTRODUCTION

Commercial cloud service providers (CSPs) offer elastic computing benefits to cloud clients in the form of variety of VMs with different resource capacities at minimum capital investment [1] which allow them to choose appropriate VMs for their applications execution and pay accordingly. However, the resource requirement changes over time that raises challenges for CSPs including inefficient resource utilization and extravagant power consumption. For instance, the effect of resources utilization deviation from their demanded capacity can be seen in Fig. 1 that shows a snapshot of resource utilization over a period of 24 hours, collected from Google Cluster dataset [2] where the CPU and memory utilization fluctuates between 5-42 and 5-60 percent respectively. It reveals that most of the time user over-subscribes the resources that results into inefficient VM placement and leads to ample amount of resource wastage and power consumption [3]. The reason behind over-subscription is that cloud clients are unaware of the actual resource usage of their applications and to avoid the risk of failure at peak time, they tend to over-estimate the resources [4]. Moreover, the network traffic scales up due to placement of inter-dependent VMs on farther located servers. Cisco Global Cloud Index predicts that by the year 2021, network traffic among the devices within data center will grow at Compound Annual Growth Rate (CAGR) of 23.4 percent [5]. Therefore, a network aware and power efficient resource management technique is needed to consolidate cloud workload on minimum number of active servers and minimize network traffic within data center [6].

The elastic resource management includes several operations like, balanced scheduling of applications and VMs, controlling of server over/under-load by applying VM migration etc. [7], each of which has been investigated individually in the existing work. For example, task scheduling is discussed in [8], [9], VM placement and migration algorithms are presented in [10], [11] and [12], [13] respectively. In the real cloud environment, all these operations work continuously in cooperative manner because the performance achieved by optimal task scheduling degrades, if VMs are not placed effectively on the server. Similarly, optimizing VM placement and ignoring optimization during VM migration cannot bring the possible power saving. Therefore, all these operations must be considered in cooperation to achieve the real benefits of performance optimization associated at different levels. Moreover, the existing literature [14] suggests that prior knowledge of upcoming workload can assist in load balancing and reduction of performance degradation due to overloads. On the other hand, SLA violations may increase due to errors in predicting future workloads. Now, the two key challenges are: (i) How to deploy prediction system at data center to assist in
the resource management? (ii) How to utilize the predicted information for improving performance of data center while avoiding risk of SLA violations?

To address aforementioned challenges, an Online VM Prediction based Multi-objective Load Balancing (OP-MLB) framework is proposed that incorporates several algorithms to work in collaboration to provide efficient resource management for cloud environment. It includes SLA aware user’s application execution on VMs followed by the multi-objective VM assignment and migration for handling of over/under-loaded servers. Furthermore, to effectively exploit over-subscription by cloud clients, an online-prediction system is developed and deployed at each VM that learns and predicts the future resource demand in parallel with application execution at respective VM to allow closer estimation of the expected resource demand beforehand. The physical resources are distributed on the basis of predicted resource demand combined with the error-driven padding (EDP) to avoid risk of SLA violations.

### 1.1 Our Contributions

The key contributions of the proposed work are:

- A novel multi-objective load-balancing approach based on online prediction i.e., OP-MLB framework is proposed for elastic resource management at cloud data center.
- A neural network based online predictor tuned with adaptive evolutionary algorithm is developed to forecast resource usage with enhanced accuracy by appending error-driven padding to predicted output.
- Multi-objective load balancing is presented with proactive VM placement and migration, where VMs are allocated subject to maximum resource utilization and minimum power consumption, communication cost. It triggers VM migration before overload occurrence to improve performance of data center.
- Substantial power saving is achieved by exploiting oversubscribed cloud, applying successive optimization at different phases and reducing number of active servers and VM migrations.
- Implementation and evaluation of proposed framework by using three real benchmark datasets reveal that proposed work outperforms the state-of-art approaches in terms of performance metrics like server overload prediction, resource utilization, reduction of power consumption and communication cost.

### Organization

Section 2 discusses related work. The overview of proposed framework is given in Section 3 followed by its detailed description including task assignment, online resource predictor and load management in Sections 4, 5 and 6 respectively. Main algorithm is presented in Section 7. The performance evaluation is presented in Section 8 followed by conclusion and future scope of the proposed work in Section 9. Table 1 shows the list of symbols with their explanatory terms that have been used throughout the paper.

### 2 RELATED WORK

The related work is organized into two subsections: (2.1) the work which predicts the resource usage before load balancing and (2.2) overload handling and VM migration techniques.

#### 2.1 Resource Prediction and Allocation Techniques

Dynamic resource allocation and VM placement were presented in [15], [16] in which future demands of the resource were predicted for energy efficient resource utilization. The future state of VMs was predicted by computing exponential weighted moving average (EWMA) based on past behaviors of VMs. Nguyen et al. [17] presented VM consolidation method based on prediction of multiple resource utilization for power efficient data centers. There was always a risk of SLA violation and resource wastage due to prediction errors. To avoid that problem, Yu et al. [18] presented stochastic load balancing, in which probabilistic distribution of prediction errors were padded to the predicted output. In addition, to handle improper VM migrations occur due to overloaded servers and inefficient resource utilization,
hotspot (overloaded servers) were identified and a heuristic algorithm was proposed to decide VM migrations from hotspot to underutilized servers and fairly allocate VMs on available servers. Later, an energy-efficient VM prediction and migration framework was proposed in [4] where Wiener filter was used for prediction of resource usage and EWMA based safety margins were appended to the predicted output to avoid the SLA violation due to errors in prediction. An Online VM placement for raising cloud provider’s revenue was proposed in [19] that employed First-Fit and Harmonic Algorithms(HA) for online VM placement and Decreased Density Greedy algorithm to handle SLA violation where HA outperformed FF for energy-efficient VM placement. Recently, Saxena et al. [20] have proposed a workload and security threats prediction based resource allocation model that considers network traffic and previous resource utilization before workload distribution on user VMs.

2.2 Overload Handling Techniques

VMs migration have been used in [21], [22] after detection of server overloads. This approach causes delay in execution of user’s application and leads to SLA violation. To overcome this limitation, threshold-based VM migration is presented in [23] where migration process is triggered before actual occurrence of overload on the basis of threshold value of server utilization. The threshold value can be set statically or depending upon workload fluctuations [23]. However, this technique might trigger unnecessary VM migrations because exceeding threshold value does not always lead to overloading of server and also under-utilized servers are not addressed that causes wastage of resources and power. To tackle these limitations, overload avoidance techniques were introduced on the basis of prediction of resource demands in [4], [17]. The prediction helps to estimate unseen over/under-load situation and decide VM migration. Energy aware VM migration is presented in [4], [24]. Dabaggh et al. [4] considered the energy consumed during VM migration and suggested to migrate VM from overloaded server to already active server and turn-ON selected inactive server only if migration is impossible on all the active servers. However, they ignored the traffic management and network bandwidth cost required during VM migration. Meng et al. [25] studied the effect of network resources while optimizing VM migration on host machines [26] and proposed a two-tier approximation algorithm to solve traffic-aware VM mapping problem that resulted into increased throughput and decreased communication cost.

Unlike existing works, OP-MLB framework provides a pragmatic solution of complex and challenging elastic resource management problem by developing and incorporating all the needed operations at unified platform and allowing interaction among them to optimize and tune/learn together to bring overall performance improvement of cloud data center.

3 FRAMEWORK OVERVIEW

The proposed OP-MLB framework incorporates three phases viz. task assignment, online VM prediction and load balancing to provide concrete and optimal solution to the problem of elastic resource management in cloud environment as shown in Fig. 2. These three phases work in collaboration by interacting with each other. In the first phase, applications \{Application$_1$, Application$_2$, \ldots, Application$_M$\} are assigned to the users \{User$_1$, User$_2$, \ldots, User$_N$\} are divided into sub-units called as tasks \{T$_1$, T$_2$, \ldots, T$_N$\}, which are assigned to computing instances called as VMs \{VM$_1$, VM$_2$, \ldots, VM$_M$\} for execution. The application model considered in the proposed framework is made up of a collection of independent tasks and it is known by many names: Bag of Tasks (BoT), Task Farming, Parameter Sweep, and SPMD (Single Program and Multiple Data) model. The applications created using this model are very common in scientific and commercial domains such as molecular docking for drug discovery [27] and investment risk analysis [28].

During second phase, VMs loaded with user’s task perform task execution as well as predict resource utilization for the next interval concurrently. The allocated VMs are shown in filled blocks whereas vacant blocks specify de-unallocated VMs. Every active VM carries distinct online-predictor depending on its configuration to forecast resource utilization information. Additionally, each server has its own load analyzer, that aggregates the predicted resource usage information of each VM and detects the occurrence of over/under-load beforehand. If the predicted resource usage is greater than the resource capacity of the server, then overload is detected and accordingly needed operations are performed to mitigate its effect in third phase.

In the third phase, load balancing is achieved by performing VM assignment and migration to improve resource utilization by effective handling of over/under-loaded servers. The load analyzer informs cluster manager about the expected load at respective server in the cluster periodically, which utilizes this information during VM allocation on the selected server by applying the multi-objective VM
4 TASK ASSIGNMENT

Consider a data center having $P$ servers such as $S \in \{S_1, S_2, \ldots, S_P\}$, where $M$ users have purchased different types of VMs to execute their applications on $Q$ VMs such as $v \in \{v_1, v_2, \ldots, v_Q\}$. Suppose an application $A_M$ of $M^{th}$ user is represented as $\{T_1, T_2, \ldots, T_q\} \in A_M$, where $T_q$ denotes $q^{th}$ task of the application. The tasks are scheduled on the basis of their resource requirement by applying Eq. (1) that selects most appropriate VM for execution of $i^{th}$ task ($T_i^r$) where, $r$ represents resources like CPU, memory etc. and $v_S$, $v_M$, $v_L$, and $v_{XL}$ are small, medium, large and extra-large type of VMs. The type of VMs can be extended to any number of types offered at particular data center. If the resource requirement of $i^{th}$ task ($T_i^r$) is lesser or equals to the resource capacity of $v_S$, then small type of VM is assigned to it. Likewise, if $(v_S^r < T_i^r \leq v_M^r)$, then $v_M$ is selected for the task execution and so on.

\[
VM_{sel} = \begin{cases} 
    v_S, & (T_i^r \leq v_S^r) \\
    v_M, & (v_S^r < T_i^r \leq v_M^r) \\
    v_L, & (v_M^r < T_i^r \leq v_L^r) \\
    v_{XL}, & \text{(otherwise)} 
\end{cases} \quad r \in \text{CPU, mem.} \quad (1)
\]

SLA is a mutual agreement between the CSP and the cloud client that guarantees availability ($A_D$) of services, throughput and response time etc. The negotiated SLA terms are monitored with respect to ‘availability’, which is computed as shown in Eq. (2) where $A_s$ and $A_D$ are availability offered and availability guaranteed respectively. The variables $a$ and $b$ are uptime and downtime of server respectively. The uptime means server is available for task execution on allocated VM and downtime states failure of task execution due to unavailability of server. Therefore, SLA violation ($SLA_v$) can be defined using Eq. (3)

\[
A_o = 1 - \frac{b}{a} \quad (2)
\]

\[
SLA_v = \begin{cases} 
    \text{No,} & A_D \leq A_o \\
    \text{Yes,} & \text{(otherwise)} 
\end{cases} \quad (3)
\]

The SLA violation experienced due to unavailability of small, medium, large and extra-large types of VMs are represented as $v_S^{SLA_v}$, $v_M^{SLA_v}$, $v_L^{SLA_v}$ and $v_{XL}^{SLA_v}$ respectively. The realized penalty cost depends on amount of SLA violation i.e., difference between $A_o$ and $A_s$ and relative standard penalty cost associated with small ($\Omega_S$), medium ($\Omega_M$), large ($\Omega_L$) and extra-large ($\Omega_{XL}$) type of VMs as shown in Eq. (4)

\[
\text{penalty} = \begin{cases} 
    (A_s - A_o) \times \Omega_S, & v_S^{SLA_v} \\
    (A_s - A_o) \times \Omega_M, & v_M^{SLA_v} \\
    (A_s - A_o) \times \Omega_L, & v_L^{SLA_v} \\
    (A_s - A_o) \times \Omega_{XL}, & v_{XL}^{SLA_v} 
\end{cases} \quad (4)
\]
\[ \Lambda_i^t = \Phi_{best}^t + \mu_i \times (\Phi_{1}^t - \Phi_{2}^t) \]  
(6)
\[ \Lambda_i^t = \Phi_{best}^t + \mu_i \times (\Phi_{best}^t - \Phi_{1}^t) + \mu_i \times (\Phi_{1}^t - \Phi_{2}^t) \]  
(7)
\[ \Lambda_i^t = \Phi_{best}^t + \mu_i \times (\Phi_{1}^t - \Phi_{2}^t) \]  
(8)

where \( \mu \) is mutation rate, \( \Lambda_i^t \) and \( \Phi_i^t \) depict \( i^{th} \) mutant and current vectors respectively, of \( j^{th} \) iteration. The term \( \Phi_{best}^t \) is the best solution found till \( j^{th} \) generation and \( r1, r2 \) and \( r3 \) are mutually distinct random numbers in the range \([1, N] \). To decide the mutation scheme for current iteration, a random vector i.e., mutation selection probability (msp) is generated in the range \([0, 1] \) for each network and updated during learning process. The mutation scheme selection parameter (\( \psi \)) chooses most suitable mutation scheme based on the value of msp, (where \( 1 \leq i \leq N \)) as given in Eq. (9), where \( \Gamma_1, \Gamma_2 \) and \( \Gamma_3 \) are the probabilities for opting the \( MS_1, MS_2 \) and \( MS_3 \) mutation schemes respectively.

\[ \psi = \begin{cases} 
MS_1, & \text{If}(0 < \text{msp}_i \leq \Gamma_1) \\
MS_2, & \text{If}(\Gamma_1 < \text{msp}_i \leq \Gamma_1 + \Gamma_2) \\
MS_3, & \text{otherwise} 
\end{cases} 
\]  
(9)

In reported experiments, initially \( \Gamma_1 = \Gamma_2 = 0.33, \Gamma_3 = 0.34 \), so that each mutation scheme get equal chance of selection. Later on, these probabilities are updated by computing the ratio of total number of successful candidates which have reached next generation through respective mutation strategy and total number of candidates generated.

Thereafter, uniform crossover is applied to mutant vector \( \Lambda_i^t \) and its corresponding current target vector \( \Phi_i^t \) to produce new solutions called as offspring \( \chi_i^t \) by applying Eq. (10) where \( R \) is randomly generated number in the range \([0, 1] \) for each gene in the chromosome (or vector). The crossover-rate is randomly generated in the range \([0, 1] \) with mean value of 0.5 and standard deviation 0.1 during each generation. If the value of \( R \) is smaller than \( i^{th} \) gene crossover-rate \( (Cr_i^t) \), crossover is successful and \( i^{th} \) genes swap between mutant and current vectors, else previous solution proceeds in the next generation.

\[ \chi_i^t = \begin{cases} 
\Lambda_i^t, & \text{If}(R \in (0, 1) \leq Cr_i^t) \\
\Phi_i^t, & \text{otherwise}. 
\end{cases} 
\]  
(10)

Finally, the selected candidates are sorted on the basis of fitness value (i.e., least RMSE score) using Eq. (5). The population for next generation is selected by applying survival of fittest concept stated in Eq. (11), where \( \Phi_i^{t+1} \) is selected candidate for next generation. \( \chi_i^t \) is solution generated after crossover and \( \Phi_i^t \) is current solution. Algorithm 1 gives operational summary of AADE training process for online resource prediction.

\[ \Phi_i^{t+1} = \begin{cases} 
\chi_i^t, & \text{fitness}(\chi_i^t) \leq \text{fitness}(\Phi_i^t) \\
\Phi_i^t, & \text{otherwise}. 
\end{cases} \]  
(11)

Error-Driven Padding (EDP). Although the proposed on-line predictor is capable of anticipating resource demands with closer precision, still 100 percent accuracy cannot be ensured for highly dynamic resource demands. These errors may cause over/under-load and SLA violations. In order to overcome the occurrence of these issues, error-driven precaution margins are padded with predicted resource demand. At \( t_{th} \) instance, EDP is computed as \( EDP_t = (1 - \rho) \times EDP_{t-1} + \rho \times \text{RMSE} \) where \( 0.5 < \rho \leq 1 \). Furthermore, it is to be noted that during EDP computation, more weightage is given to most recent error to improve the accuracy of prediction. Therefore, the improved predicted output becomes \( z_p + EDP_t \).

6 LOAD MANAGEMENT

Load balancing includes two main processes (i) VMs placement on servers and (ii) VM migration, discussed in the following subsections.

6.1 VM Placement

Assume \( S^C_i \) and \( S^M_i \) are CPU and memory capacity of \( i^{th} \) server. If server \( S_i \) is active then \( \gamma_i = 1 \), means one or more VMs are placed on it, otherwise, it is idle (\( \gamma_i = 0 \)). If server \( S_i \) hosts VM \( v_j \), then \( \omega_{ji} = 1 \) else it is 0. For \( j^{th} \) VM (\( v_j \)), CPU and memory utilization are represented as \( v_j^C \) and \( v_j^M \) respectively. The CSP always seeks an optimal VM placement that maximize resource utilization and minimize power consumption and network traffic to achieve maximum return-on-investment (ROI). Therefore, multi-objective VM placement problem is formulated as stated in Eq. (12)

\[ \sum_{i=1}^{PQ} \omega_{ji} = \min \left( \sum_{i=1}^{PQ} \omega_{ji} \times (PW, Com, -RU) \right), \]  
(12)

where \( PW, Com \) and \( RU \) are power consumption, communication cost and resource utilization respectively of \( j^{th} \) server. Each VM allocation is feasible only if it satisfies the following constraints given in Eq. (13)
To accomplish this multi-objective VM placement, following objective models are designed:

### 6.1.1 Resource Utilization

The resource utilization of data center can be obtained using Eqs. (14), (15), where \( R \) is number of resources. Though in formulation, only CPU (\( C \)) and memory (\( M \)) are considered, it is extendable to any number of resources

\[
RU_{dc} = \int_{t_1}^{t_2} \left( RU_{dc}^C + RU_{dc}^M \right) dt
\]  

\[
RU_{dc}^r = \sum_{i=1}^{P} \sum_{j=1}^{Q} \omega_{ji} \times \frac{x^r_j}{S_i} \quad r \in \{CPU, Mem, etc.\}
\]

### 6.1.2 Communication Cost

Let \( \beta_{ik} \) denotes mapping between server \( S_i \) and user \( u_k \), if a user \( u_k \) owns VMs on server \( S_i \), then \( \beta_{ik} = 1 \) otherwise 0.

The total number of users having inter-dependent VMs are computed as \( \sum_{j=1}^{M} \sum_{i=1}^{P} \beta_{ij} \). The communication cost model is shown in Eq. (16) where \( |U| \) is total number of active users and \( Com_{dc} \) is communication cost of data center which is minimized. The inter-dependent VMs are preferably allocated at minimum number of servers to reduce communication cost among inter-dependent VMs

\[
Com_{dc} = \int_{t_1}^{t_2} \left( \frac{100 \times \sum_{i=1}^{P} \beta_{ik}}{|U|} \right) dt; \quad \forall \sum_{i=1}^{P} \beta_{ik} > 1.
\]

### 6.1.3 Power Consumption

From existing literature [29], power consumption for \( j^{th} \) server can be formulated as \( PW_j \) and total power consumption \( PW_{dc} \) during time-interval \( [t_1, t_2] \) is shown in Eq. (17)

\[
PW_{dc} = \int_{t_1}^{t_2} \left( \sum_{i=1}^{P} \left( |PW_{j_{max}}^i - PW_{j_{min}}^i| \times RU + PW_{j_{idle}}^i \right) \right) dt.
\]

where \( RU \) is resource utilization, \( PW_{j_{max}}, PW_{j_{min}} \) and \( PW_{j_{idle}} \) are maximum, minimum and idle state power consumption for \( j^{th} \) server.

### 6.1.4 Optimized VM-Allocation Approach

The proposed multi-objective VM allocation approach consists of four consecutive stages namely initialization, fitness evaluation, crossover and selection as shown in Fig. 4.

The VM allocations are represented as chromosomes (\( \Psi \)) and the step-by-step procedure is given in Algorithm 2. First, \( n \) random VM allocations are initialized as \( \Psi_{i} \) (step 1) which represents \( i^{th} \) VM placement, subject to \( i \leq n \). To evaluate fitness of each chromosome, cost function \( \eta(\Psi) \) is computed, where \( f^{RU}, f^{Com}, f^{PW} \) are cost values associated to resource utilization, communication cost, power consumption and can be evaluated by computing Eqs. (14), (16) and (17) respectively (step 2). A Pareto-front module is called in step 3 to generate

### Algorithm 2. VM Placement

1: Initialize \( n \) random VM allocations \( \{\Psi_{1}, \Psi_{2}, \ldots, \Psi_{n}\} \in \Psi \)
2: \( [f^{RU}, f^{Com}, f^{PW}] = \eta(\Psi) \)
3: \( \Psi_{front} = Pareto - front(\Psi) \)
4: for \( g = 1, 2, \ldots, n_{max} \) do
5: for each \( i=(1,2,\ldots,n) \) do
6: \( r_n = random(1,n) \), \( cp = random(1,P) \)
7: \( \Psi_{Cr_{1}} = \Psi_{i(1:cp)} \), \( \Psi_{rn(cp+1:P)} \)
8: \( \Psi_{Cr_{2}} = \Psi_{rn(1:cp)} \), \( \Psi_{i(cp+1:P)} \)
9: \( \Psi_{Off} = \Psi_{Cr_{1}} \), \( \Psi_{Cr_{2}} \)
10: \( \Psi_{Off} = feasible VM Allocation(\Psi_{Off}) \)
11: \( [f^{RU}_{Off}, f^{Com}_{Off}, f^{PW}_{Off}] = \eta(\Psi_{Off}) \)
12: end for
13: \( \Psi_{g+1} = Pareto - front(\Psi_{g}) \)
14: end for
6.2 VM Migration
The VMs allocation is re-optimized during consecutive prediction intervals by migrating VMs from predicted under/over-utilized to optimal servers. The cost of VM migration mainly depends on size of VM and network bandwidth [31]. In OP-MLB, largest resource capacity VM is chosen for migration from overloaded server to allow efficient resource utilization while mitigating the effect of current overload and need of VM migration in the near future. To allow network aware VM migration, inter-dependent VMs are shifted closer to each other which reduces total network traffic and VM migration cost. The selection of destination server is energy-efficient also because it first tries to shift migrating VM (\(v_{\text{mig}}\)) to already active server in closer location and switch to nearby inactive server only if the migrating VM cannot be shifted to any active server. The necessary constraint for VM migration is that required resource capacity of \(v_{\text{mig}}\) must be lesser than available resource capacity of destination server \(S_j\) as defined in Eq. (18), where, \(r\) represents resources like CPU, memory

\[
v_{\text{mig}} \leq S_j^r \quad r \in \{\text{CPU, Mem.}\}
\]  

(18)

Moreover, to further reduce power consumption, the VMs running on under-utilized servers migrate to near-by optimal server and idle servers are shutdown. It allows consolidation of VMs with reduced power consumption and network communication cost. The total migration cost \(M_{\text{cost}}\) for period between \(t_1\) and \(t_2\) can be computed using Eq. (19)

\[
M_{\text{cost}} = \int_{t_1}^{t_2} \left( \sum \eta_{\text{mig},j} 
\times (D(S_k, S_j) \times W(v_{\text{mig}})) + \sum n_j \times d_j \right) dt,
\]

(19)

where \(v_{\text{mig}} \in O, j \in [1, P]\), \(D(S_k, S_j)\) is the distance or number of hops covered by \(v_{\text{mig}}\) from source \((S_k)\) to destination server \(S_j\), \(W(v_{\text{mig}}) = \eta_{\text{mig}} \times v_{\text{mig}}\) is the size of migrating VM, \(O\) is the list of VMs on overloaded server \((S_i)\). The first term \(\sum \eta_{\text{mig},j} \times D(S_k, S_j) \times W(v_{\text{mig}})\) signifies network energy consumed during VM migration. The second term \(\sum n_j \times d_j\) signifies server state transition energy, where if \(i^{th}\) VM is placed at \(j^{th}\) server after migration then \(c_{\text{mig},j} = 1\), otherwise, \(c_{\text{mig},j} = 0\). If \(j^{th}\) server receives one or more VMs after migration, then \(n_j = 1\) else it is 0. Similarly, if \(d_j = 0\) then \(j^{th}\) server is already active before migration, otherwise, \(d_j = E_{ir}\) where \(E_{ir}\) is energy consumed in switching a server from sleep to active state. In proposed work, the value of \(E_{ir}\) = 4260 Joules as stated in [32]. Algorithm 3 provides operational steps of VM migration.

7 OP-MLB: MAIN ALGORITHM AND COMPLEXITY
Algorithm 4 depicts the operational summary of OP-MLB framework which executes periodically to process elastic resource management. In steps 1-3, resource usage of each VM is predicted by calling Algorithm 1, which provides training steps for NN predictor whose time complexity depends on size of network (L), number of networks (N), number of input nodes (p) and \(G_{\text{max}}\) that becomes \(O(p^2NLG_{\text{max}})\).

Step 4 calls multi-objective VM placement module, provided in Algorithm 2 that works on number of solutions (\(n\)), generations \((G_{\text{max}})\), servers \((P)\), VMs \((Q)\) that calls Pareto-optimal based on NSGA-II, having time complexity of \(O(n^2 \times o)\) where \(o\) is number of objectives. Hence, overall time complexity is \(O(on^2PQ(G_{\text{max}}))\). Steps 5-18 handle over/under-load by calling VM migration i.e., Algorithm 3. Steps 11 and 12 prepare list of overloaded servers by using predicted load information, given by steps 7-10. The steps 13-15 detect and handle under-loaded servers and step 16 calls Algorithm 3 to handle overloaded servers. The time consumption depends on number of over-loads \((O_S)\), number of servers \((P)\) which becomes \(O(PQ)\) as

Algorithm 3. VM Migration \((O_S)\)

1: for each \(j^{th}\) server \(S_j \in O_s\) do
2: Sort VMs in ascending order of resource capacity
3: \(v_{\text{mig}} \leftarrow \) Pick the best suited VM from sorted list to mitigate the effect of overload
4: for each \(i^{th}\) server \(S_i\) do
5: if status((\(S_i)) = 'ACTIVE' AND Eq. (18) satisfies then
6: \(v_{\text{mig}} \leftarrow\) Update status(\(v_{\text{mig}}\))='Assigned'
7: end if
8: end for
9: if status(\(v_{\text{mig}}\)) /= 'Assigned' then
10: for each \(k^{th}\) server \(S_k\) do
11: \(v_{\text{mig}} \leftarrow\) nearby SLEEPING server that satisfy Eq. (18); status((\(S_k)) = 'ACTIVE' and status(\(v_{\text{mig}}\)) = 'Assigned'
12: end for
13: end if
14: Compute Migration cost using Eq. (19)
15: end for


1: for each \(i^{th}\) VM on \(S\) and \((S_1, S_2, \ldots, S_P) \in S\) do
2: \(v_{\text{pred,C}}, v_{\text{pred,M}} \leftarrow\) Algorithm 1()+EDP
3: end for
4: CALL VM placement()
5: for \(i^{th}\) time-interval do
6: for each \(j^{th}\) server \(S_j\) do
7: for each \(i^{th}\) VM on \(S_j\) do
8: \(v_{\text{pred,C}}, v_{\text{pred,M}} \leftarrow\) Algorithm 1()+EDP
9: \(S_j^{C} = v_{\text{pred,C}} + S_j^{C}, S_j^{M} = v_{\text{pred,M}} + S_j^{M}\)
10: end for
11: if \(S_j^{C} \cdot \text{Max_threshold} \leq S_j^{C} \text{ OR} S_j^{M} \cdot \text{Max_threshold} \leq S_j^{M}\) then
12: Server \(S_j\) is over-loaded. \(O_S \leftarrow S_j\)
13: else if \(S_j^{C} \cdot \text{Min_threshold} \geq S_j^{C} \text{ OR} S_j^{M} \cdot \text{Min_threshold} \geq S_j^{M}\) then
14: Server \(S_j\) is under-loaded, shift all VMs to nearby ACTIVE servers subject to constraints mentioned in Eq. (18) and shutdown it.
15: end if
16: CALL VM-migration(\(O_S\))
17: end for
18: end for
19: Repeat above steps for next time-interval
Therefore, the total time complexity can be computed as $O(n^2 N^2 P^2 Q(G_{max})L)$.

8 PERFORMANCE EVALUATION

8.1 Experimental Set-Up

The simulation experiments are executed on a server machine assembled with two Intel® Xeon® Silver 4114 CPU with 40 core processor and 2.20 GHz clock speed. The computation machine is deployed with 64-bit Ubuntu 16.04 LTS, having main memory of 128 GB. The data center environment was set up with three different types of server and four types of VMs configuration shown in Tables 2 and 3 in Python version-3. The resource features like power consumption ($P_{max}$, $P_{min}$), MIPS, RAM and memory are taken from real server IBM [33] and Dell [34] configuration where $S_1$ is 'ProLiantM110G5Xeon3075', $S_2$ is 'IBMx3250Xeonx3480' and $S_3$ is 'IBM3550Xeonx5675'. Furthermore, the experimental VMs configuration are inspired from the VM instances of Amazon website [35]. The resource utilization for different VMs followed the traces from three publicly available real workloads including Google Cluster Data (GCD), PlanetLab VMs (PL) and Bitbrains (BB) dataset. GCD has resources CPU, memory, disk I/O request and usage information of 672,300 jobs executed on 12,500 servers for the period of 29 days [2]. The CPU and memory utilization percentage of VMs are obtained from the given CPU and memory usage percentage for each job in every five minute over period of twenty-four hours. PL contains CPU utilization of more than 11K VMs measured every five minutes during ten random days in March-April, 2011 [36]. BB consists of performance metrics of fast storage 1,750 VMs from a distributed data center over period of 30 days [37]. It gave information about CPU usage percentage, disk I/O etc. We extracted CPU and memory usage percentage from GCD and CPU percentage from PL and BB as per their availability for various experiments. The experiments are conducted for different size of data center over period of 24 hours for GCD and PL and 30 days for BB. Following performance metrics are evaluated:

- Accuracy of Predicted vs Actual Workload.
- Resource utilization and power consumption.
- Communication cost percentage.
- Number of predicted and unpredicted overloads.
- VM migration cost incurred during load balancing.

8.2 Results

The performance evaluation of the proposed framework starts with investigation of accuracy of online-prediction system. Its effectiveness can be seen in Fig. 5 where predicted CPU usage have almost overlapped actual resource usage for GCD, PL and BB workloads. The error score of proposed prediction approach for prediction interval of 5 minutes on three workloads is shown in Table 4.

The reason behind such an accuracy is that proposed neural network based predictor periodically learns and retrains itself according to changes in live and historical workload. In addition, the application of AADE algorithm works on $N$ number of solutions which explores the search space in multiple directions and allows efficient learning of patterns and correlations from live data which is responsible for near accurate prediction of resources.

To analyze the performance of multi-objective load balancing, numerous experiments were conducted based on different combination of VMs and servers. The experiments are executed with the ratio of number of VMs and servers

![Fig. 5. Predicted versus actual workload.](image-url)
as 1:1. It is mentioned that resource utilization (RU) percentages per VM extracted from the three workloads are used to compute the actual resource usage of VMs under simulation. For instance, if real workload trace shows 67.3 percent of CPU usage and VM has 500 MIPS of CPU capacity then actual CPU usage of the VM is given by the product of 67.3 percent and 500. The number of users are not mentioned in the original datasets, therefore, we created random set of users, who requested different number and type of VMs to compute communication cost (Com) based on the location of inter-dependent VMs. The number of users are taken as 60 percent of size of the data center, where each user can hold VMs in the range between 0 and 5 with a constraint that at any instance, the total number of VM requests must not exceed total number of VMs of data center. Each experiment was executed for 12-15 times and a mean of the obtained results are reported. In the simulation, various performance metrics were analyzed and results are shown in Tables 5, 6 and 7 for GCD, PL and BB workloads respectively. The values of minimum and maximum threshold of CPU usage were 10 and 89 percent respectively for these experiments. The resource utilization for each workload is depending upon the number of active servers shows slight change with different size of data center for each dataset. However, power consumption and VM migration costs are increasing with respect to the size of the data center. The values for SLA compliance are varying according to the availability/non-availability of servers.

The pareto-front or non-dominated solutions for 1,400 VMs placement is shown in Fig. 6 that depicts the contradictory behavior of three optimization variables viz. maximization of RU, minimization of PW and Com. Fig. 7 shows the predicted and unpredicted overloads for all three datasets. It is noted that there is an increase in the number of correctly predicted overloads on the respective servers with increase in size of data center for all the three workloads. However, the number of unpredicted overloads are either lesser or equal to 0.07 percent independent of size of the data center for each experiment of every dataset. This is due to the efficiency of prediction system that accurately forecasts the future resource requirement. The overload prediction accuracy is around 99.94 percent for GCD during the period of 24 hours. Similarly, more than 99.91 and 99.97 percent overloads are correctly forecasted for PL and BB respectively. As a result, the number of VM migrations and SLA violations get reduced during actual VMs allocation which can be observed in Fig. 8. Since SLA violations depends upon the availability of the server, they are indirectly varying with respect to the number of unpredicted overloads for different size of the data center. The number of unpredicted overloads prompt VM migration and unavailability of server and hence account for SLA violation.

![Multi-objective Pareto Front for 1400 VMs with GCD.](image)

**Table 4**

<table>
<thead>
<tr>
<th>Interval</th>
<th>GCD (CPU)</th>
<th>GCD (Memory)</th>
<th>PL (CPU)</th>
<th>BB (CPU)</th>
</tr>
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<tr>
<td>5 min</td>
<td>0.0014</td>
<td>0.0035</td>
<td>0.0005</td>
<td>0.0031</td>
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**Table 5**

<table>
<thead>
<tr>
<th>VMSs (Users)</th>
<th>RU(%)</th>
<th>PW</th>
<th>Com(%)</th>
<th>$M_{cost}$ (KJ)</th>
<th>$SLAv$ (×10⁻³)(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 (120)</td>
<td>64.98</td>
<td>8.80E+03</td>
<td>11.78</td>
<td>15.4</td>
<td>4.53</td>
</tr>
<tr>
<td>400 (240)</td>
<td>64.57</td>
<td>1.96E+04</td>
<td>12.8</td>
<td>169</td>
<td>2.44</td>
</tr>
<tr>
<td>600 (360)</td>
<td>64.05</td>
<td>2.17E+04</td>
<td>12.23</td>
<td>294</td>
<td>2.25</td>
</tr>
<tr>
<td>800 (480)</td>
<td>63.34</td>
<td>3.31E+04</td>
<td>12.34</td>
<td>278</td>
<td>3.22</td>
</tr>
<tr>
<td>1000 (600)</td>
<td>63.87</td>
<td>3.59E+04</td>
<td>12.32</td>
<td>306</td>
<td>5.52</td>
</tr>
<tr>
<td>1200 (720)</td>
<td>63.32</td>
<td>3.92E+04</td>
<td>12.25</td>
<td>384</td>
<td>3.93</td>
</tr>
<tr>
<td>1400 (560)</td>
<td>63.09</td>
<td>4.13E+04</td>
<td>12.4</td>
<td>404</td>
<td>5.63</td>
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**Table 6**

<table>
<thead>
<tr>
<th>VMSs (Users)</th>
<th>RU(%)</th>
<th>PW</th>
<th>Com(%)</th>
<th>$M_{cost}$ (KJ)</th>
<th>$SLAv$ (×10⁻³)(%)</th>
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<tr>
<td>200 (120)</td>
<td>68.98</td>
<td>5.64E+03</td>
<td>10.14</td>
<td>55.7</td>
<td>2.69</td>
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<tr>
<td>400 (240)</td>
<td>69.57</td>
<td>1.94E+04</td>
<td>11.438</td>
<td>346</td>
<td>3.52</td>
</tr>
<tr>
<td>600 (360)</td>
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<td>2.14E+04</td>
<td>11.43</td>
<td>389</td>
<td>3.24</td>
</tr>
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<td>10.34</td>
<td>364</td>
<td>1.52</td>
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<tr>
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<td>2.04</td>
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<tr>
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<td>3.96E+04</td>
<td>11.25</td>
<td>414</td>
<td>2.15</td>
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<tr>
<td>1400 (840)</td>
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**Table 7**

<table>
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<tr>
<th>Users</th>
<th>RU(%)</th>
<th>PW</th>
<th>Com(%)</th>
<th>$M_{cost}$ (KJ)</th>
<th>$SLAv$ (×10⁻³)(%)</th>
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</thead>
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<tr>
<td>200</td>
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<td>1.37E+03</td>
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<td>62.4</td>
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<td>400</td>
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<td>2.84E+04</td>
<td>13.8</td>
<td>243</td>
<td>2.44</td>
</tr>
<tr>
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<td>64.05</td>
<td>3.20E+04</td>
<td>13.23</td>
<td>267</td>
<td>3.85</td>
</tr>
<tr>
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<td>64.34</td>
<td>3.31E+04</td>
<td>15.34</td>
<td>378</td>
<td>4.62</td>
</tr>
<tr>
<td>1000</td>
<td>65.87</td>
<td>4.59E+04</td>
<td>16.32</td>
<td>316</td>
<td>4.52</td>
</tr>
<tr>
<td>1200</td>
<td>64.32</td>
<td>6.92E+04</td>
<td>13.25</td>
<td>484</td>
<td>3.93</td>
</tr>
<tr>
<td>1400</td>
<td>64.32</td>
<td>8.20E+04</td>
<td>14.4</td>
<td>554</td>
<td>6.83</td>
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</table>
8.3 Comparative Analysis
The comparison of unpredicted overloads among proposed and existing approaches [4] for over-subscribed cloud is shown in Fig. 9. The reason for such comparison is that the experiments were conducted using same dataset i.e., GCD and experiments are executed for same period of 24 hours. They applied Wiener Prediction (WP) scheme for overload prediction, separately on each VM (similar to proposed approach). Therefore, it is suitable for comparison of the number of overload predicted by proposed prediction (PP) approach. It can be seen that the number of unpredicted overloads have significantly reduced in case of PP as compared to Wiener prediction (WP) with safety margin (SM) i.e., (WP+SM) and other existing approaches mentioned in [4]. The unpredicted overloads are further reduced when PP was combined with EDP.

The total number of active servers are compared with another recent work [17]. The reason for such comparison is that this work used same datasets viz. GCD and PL and their entire experimental set-up including size of different data center, types and configuration of VMs and physical servers are similar to our OP-MLB Framework. Fig. 10 entails the comparison of total number of active servers percentage for GCD and PL workloads during the entire testing period of 24 hours for 1,400 VMs among the proposed and the existing VM selection approaches, including Static THReshold (THR), Dynamic threshold based on Local Regression (LR), Static THReshold with Multiple Usage Prediction (THR-MUP) and Dynamic threshold based on Local Regression with Multiple Usage Prediction (LR-MUP) [17]. In case of both GCD and PL workloads, the percentage of active servers for the proposed approach is slightly equal or more than existing approaches due to more constrained VM placement. The proposed multi-objective approach applies an additional, but significant constraint of minimizing communication cost along with maximization of resource utilization. The VM placement is decided by the pareto-front that does not allow excessive consolidation of VMs.

Furthermore, First Fit (FF), Best Fit (BF) and Random Fit (RF) heuristics are chosen for comparison of proposed VM placement because they are baseline algorithms and many improved VM placement approaches have been developed by modifying them. Therefore, FF [38], [39], BF [36], [41] and RF [40] algorithms are implemented without oversubscription (or prediction) and with oversubscription (i.e., with our online NN based prediction) for comparison. In the figures, given ahead, proposed multi-objective load balancing (MLB) strategy with oversubscription (P1) is compared to FF, BF and RF with oversubscription denoted as F1, B1 and R1 respectively. Moreover, the proposed MLB without oversubscription (or prediction) and with oversubscription (i.e., with our online NN based prediction) for comparison. In the figures, given ahead, proposed multi-objective load balancing (MLB) strategy with oversubscription (P1) is compared to FF, BF and RF with oversubscription denoted as F1, B1 and R1 respectively. Moreover, the proposed MLB without oversubscription (i.e., P2) is compared with FF, BF and RF without oversubscription stated as F2, B2 and R2 respectively. The comparative resource utilization is shown in Fig. 11, where proposed approach shows closer to [63-65], [68-69.5] and [63-65.8] percent of resource utilization for...
GCD, PL and BB workloads respectively. The FF, BF, RF heuristics based load balancing schemes follows the resource utilization trend as BF > FF > RF for each workload. The OP-MLB shows substantial improvement in the resource utilization as compared to existing approaches. Specifically, it entails improvement up to 89.3 percent, 84.3 percent, 62.4 percent over R2 and 23.9 percent, 24.9 percent, 26.6 percent over B1 for BB, PL and GCD workload traces respectively. Additionally, these graphs reveals that for every type of VM allocation approach, application of online resource prediction scales up and improves their overall performance for each performance metrics (resource utilization and power consumption).

The reason for such improved resource utilization is that proposed MLB applies evolutionary optimization approach that works on \( N \) number of solutions and searches for the most optimal and feasible VM allocation, among multiple VM allocations. On the other hand, FF, BF and random heuristics are bin-packing algorithms which find out single solution that fit according to the concept of heuristic. Moreover, it is difficult to attain pareto-optimal solution that can satisfy (non-dominated) multiple constraints simultaneously with these heuristics. In addition, power consumption is computed for different VM allocations by using all the four approaches discussed above with oversubscription, and without oversubscription. Fig. 12 shows the power usage differences.

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**Fig. 10.** Comparison of proposed framework with existing work for percentage of active servers per data center.

**Fig. 11.** Comparison of resource utilization trend per data center for different workloads.

**Fig. 12.** Comparison of power consumption per data center for different workloads.
consumption per data center for different workloads. It was observed that proposed approach scales down power consumption up to 84.01 percent, 78.9 percent over B2 and 77.8 percent over R2 for BB, PL and GCD workloads respectively. Furthermore, the power consumption by the proposed approach, is reduced up to 69.67 percent with oversubscription, as compared to without oversubscription for BB workload.

Fig. 13 shows the comparison of overall power saving percentage per data center for three different workloads, which is achieved by adapting proposed framework in oversubscribed over non-oversubscribed cloud. There is substantial improvement in power savings which follows the order: GCD ≤ PL ≤ BB. Furthermore, it is observed that power saving percentage is highest for data center with 200 VMs and then slowly decreases with the increase in the size of the data center and finally the power saving becomes static and reaches between 35-42 percent independent of size of the data center. This due to the reduction in the number of active servers and VM migrations with utilization of proposed framework in oversubscribed cloud. However, maximum reduction of power consumption is noticed in case of BB workloads. This is due to the fact that there were approximately 40-45 percent of VMs in BB dataset that shows CPU utilization percent less than 1 percent, which is correctly predicted by our online resource forecast system and therefore, power consumption is reduced with reduction in the number of active servers.

9 CONCLUSIONS AND FUTURE WORK
In this work, elastic resource management problem is addressed by proposing an online prediction based multi-objective load balancing framework. The objectives of the proposed framework are to effectively utilize the oversubscribed cloud environment to reduce power consumption and raise resource utilization while minimizing risk of SLA violation. Moreover, the communication cost aware multi-objective load balancing was applied to minimize network traffic within the data center. The performance evaluation shows that the proposed work maximizes resource utilization and minimizes performance degradation due to overloads, number of active servers, communication cost within data center, SLA violations and power consumption. All the results are supported by the simulation and experiments executed on three different real workload traces. The comparison with state-of-art techniques states that the proposed framework can significantly improve the power savings by rightly exploiting oversubscription environment at cloud data center. In future, the proposed framework can be extended with more objectives like trust and reliability based VM allocation scheme. Additionally, the tasks can be grouped based on predicted resource utilization to allow proactive autoscaling of VMs and improve performance of data center cloud.

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REFERENCES


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