ENERGY-EFFICIENT VIRTUAL MACHINE PLACEMENT ALGORITHMS: A QUALITATIVE COMPARISON

Cloud Computing

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Abstract : Cloud computing though a popular technology, is accompanied by various challenges and energy-efficiency is one of them. Energy efficiency can be achieved in various cloud computing infrastructure domains. Cloud computing infrastructure comprises of hardware and software domains. Cloud Management System (CMS) comes under software domain. Since virtualization is the backbone of cloud computing- Virtual Machine (VM) placement, VM scheduling, VM reconfiguration, VM migration, VM consolidation can be studied to achieve energy-efficiency. These methods come under the CMS domain. In this work the problem of VM placement is considered. VM placement algorithms are classified based on multiple criteria A qualitative study is done which compares different energy-efficient VM placement algorithms.

***IndexTerms* - Cloud computing, Energy-efficiency, Virtual Machine, VM placement, Cloud Management System (CMS).**

I. INTRODUCTION

Cloud is a nebulous interconnection of computers and servers accessed by the internet [1]. Cloud computing is a paradigm focused to deliver computing as a utility [2]. Cloud data centers consume huge amount of energy and leave a high carbon footprint on the environment [3]. Energy efficiency refers to reduction of energy used for a given purpose as defined by World Energy Council [26]. To achieve energy efficiency in cloud computing there is a need to minimize energy loss and energy waste.

There are four domains in cloud computing architecture where energy efficient techniques can be applied to minimize energy loss and energy waste. Within each main domain there are sub-domains which can be researched individually for energy efficiency techniques and implementation. The network domain can be broken down into data center network, inter-data center network and end user network. Server domain can be broken down into enclosure, racks, and components. CMS domain consists of virtualization, monitoring system, and scheduler. The last domain i.e. appliance domain consists of application, runtime environment, operating system.

There are four approaches to mitigate energy savings at the CMS level which are either through reconfiguration, placement, scheduling, or migration and consolidation of VMs. VM reconfiguration is done to reduce stress on system and energy consumption. Physical machines can be adjusted to load or self-adapting VMs to resource demand can be developed or middleware can adapt resources' demand to need. VM placement involves optimization for placement of VMs on physical machines which is done by various ways like best fit-heuristics or sorting of servers [4]. VM scheduling techniques include scheduling algorithms which are used for scheduling VM requests to physical machine of particular data center over time as per requirements fulfilled with the requested resources. Scheduling algorithms can be static (for e.g. first come first serve), dynamic (for e.g. genetic algorithms), greedy algorithms (for e.g. round robin algorithms) or rank based [6]. VM migration and VM consolidation states that VMs can be moved either offline or online between physical machines so as to consolidate load on fewer machines and powering off the unused machines [4].

The rest of the paper is organized as follows. In Section II Virtualization and Cloud Computing is discussed. Section III describes about VM placement. Section IV gives literature review. Section V states Research Methodology. Section VI depicts the Results. Section VII concludes the study.

II. VIRTUALIZATION AND CLOUD COMPUTING

Virtualization is the creation of a virtual version of a server, a desktop, a storage device, an operating system or network resources. A VM provides an environment that is logically separated from the underlying hardware. The machine on which the VM is going to create is known as host machine and that VM is referred as a guest machine. There are different types of virtualization namely hardware virtualization, software virtualization, storage virtualization, server virtualization [35].

The technologies used by cloud computing are not new but cloud computing brings together the existing technologies such as virtualization, utility based pricing, distributed computing to meet today's demands. It leverages virtualization technologies at various levels (hardware and application platform) to achieve resource sharing and dynamic resource provisioning. Virtualization technology results in the abstraction of the details of physical hardware from virtualized resources for high-level applications. A virtualized server is commonly called a VM. Virtualization forms the foundation of cloud computing, as it provides the capability of pooling computing resources from clusters of servers and dynamically assigning or reassigning virtual resources to applications on-demand including physical servers, routers, switches, power and cooling systems [5].

A VM is a software implementation of a machine which executes programs just like physical machine. Since virtualization is a core technology of cloud computing, the problem of VM placement is an important topic for improving power efficiency and resource utilization in cloud infrastructures [7].

Virtualization has re-emerged recently as an approach to increase resource utilization and reducing IT service costs. The common theme of all virtualization technologies is hiding the underlying infrastructure by introducing a logical layer between the physical infrastructure and computational processes [8]. At a fundamental level, virtualization enables the abstraction or decoupling of application payload from the underlying physical resource which means that the physical resource can then be carved up into logical virtual resources as need demands referred to as provisioning. Dynamic provisioning is the capability to increase or decrease logical resources w.r.t demand [9].

With server virtualization, a control program (hypervisor or VMM) partitions the physical servers into multiple virtual servers. All VM related-operations are controlled by VMM. There are two types of hypervisors-type 1 and type 2. Type 1 hypervisors also known as "native" or "bare metal" or "embedded" hypervisors run directly on the system hardware. Type 2 hypervisors run on a host operating system. Type 1 hypervisors are more popular as they provide higher performance, availability, and security than Type 2 hypervisors [36].

III. VIRTUAL MACHINE PLACEMENT

The process of selecting the most suitable host for the VM while deploying a VM on a host is known as VM placement. During placement, hosts are rated based on the VM's hardware and resource requirements and the anticipated usage of resources. Host ratings also take into consideration the placement goal: either resource maximization on individual hosts or load balancing among hosts. The administrator selects a host for the VM based on the host ratings [37].

The mapping from VMs to physical machines/hosts is referred to as VM placement. The process of selecting a most suitable host to deploy VM is VM placement. So a VM placement algorithm aims at determining the most optimal VM to PM (Physical Machine) mapping whether it is an initial VM placement or a VM placement after migration for re-optimization [10].

VM placement algorithms are employed in/with other techniques of VM migration, VM consolidation, VM scheduling, VM reconfiguration to enhance the goal of energy efficiency in many research papers. The VM placement problem is the problem of finding a suitable placement for VMs driven by different goals. Mathematically, the VM placement problem can be stated as:

Let a physical host list is given H_{list}= {H1, H2… Hn}

And VMM has received VM requests and stored in a queue

V_{queue}= {V1, V2, V3…Vn}

Then, the mapping from the H_{list} to V_{queue} w.r.t goal of VM placement is known as VM Placement Problem (VMPP). The VM placement problem is generally considered as NP- hard problem so it is difficult to find a solution in polynomial time complexity so various heuristics are presented to solve such kind of problems.

Efficiency of cloud computing system depends on techniques used for VM placement.VM placement algorithms can be categorized based on goals-power management and QoS [18].

Another type of VM placement approaches' classification is based on single-objective or objective-objective broadly or on the basis of objective as energy consumption minimization, cost minimization, network traffic minimization, resource utilization, QoS maximization. Considering the goal of energy efficiency VM placement algorithms can be classified based on the approaches used in each as some minimize the DC power, others reduce the number of PMs turned on, and others focus on minimizing the network power consumption [11].

Energy efficiency can be achieved at server level by consolidation and virtualization, at data center level by migration, power on/off severs, prediction based-algorithms, green SLA-aware techniques, and at geo-distributed data centers by using VM placement and migration, workload placement and distribution, economy-based cost aware techniques, data center characteristics like location and configuration aware techniques[3].

IV. LITERATURE REVIEW

Yongqiang Gao et al. [7] presented a multi-objective ant colony system algorithm VMPACS for VM placement with a goal to simultaneously minimize total resource wastage and power consumption. Atefeh Khosravi et al. [12] proposed a VM placement algorithm, Energy and Carbon-Efficient (ECE) cloud architecture which benefits from distributed cloud data centers with different carbon footprint rates, PUE value, and different physical servers' proportional power. Nguyen Quang-Hung et al. [13] presented a Genetic Algorithm for Power-Aware (GAPA) VM allocation in private cloud. Dapeng Dong and John Herbert [14] gave energy efficient VM Placement supported by data analytic service i.e. the R decision support system rDSS. H. M. Ali and Daniel C. Lee [15] presented a BBO algorithm for energy efficient virtual machine placement. Toni Mastelic et al. [4] presented survey on energy efficiency in cloud computing. Christina Terese Joseph et al. [16] presented a Family Genetic Approach (FGA) for VM allocation. T. Thiruvenkadam and P. Kamalakkannan [17] gave an energy efficient multi-dimensional host load aware algorithm for VM placement and optimization in cloud environment. Ankita Choudhary et al. [18] have done a critical analysis of dynamic energy efficient virtual machine placement techniques. H. M. Ali and Daniel C. Lee [19] presented Information-based Enhanced Fire-Works Algorithm (IEFWA) and a hybrid IEFWA/BBO algorithm. Atefeh Khosravi et al. [20] presented a dynamic VM Placement method for minimizing energy and carbon cost in geographically distributed Cloud data centers. Esha Barlaskar et al. [21]

presented an energy-efficient VM placement using enhanced firefly algorithm. Xiaoning Zhang et al [22] presented a performance-aware energy-efficient Virtual Machine placement in cloud data center. Riaz Ali et al. [23] proposed a VMR: Virtual Machine Replacement Algorithm for Energy-Awareness in Cloud Data Centers without reducing the Quality of Service (QoS) for user's deadline requirements in cloud data centers. Qian Zhang et al. [24] presented an energy-aware VM placement with periodical dynamic demands in cloud datacenters. Meera Vasudevan et al. [25] proposed a Repairing Genetic Algorithm (RGA) for energy-efficient application assignment in profile-based data center management with a 3-level architecture. Wissal Attaoui and Essaid Sabir [11] presented a literature review on multi-criteria virtual machine placement in cloud computing environments.

V. RESEARCH METHODOLOGY

Various websites, research papers, journals, surveys were studied related to VM placement in cloud computing. A qualitative and theoretical research methodology was used.

VI. RESULTS

Different VM placement approaches have been devised till date to achieve energy-efficiency. In this work a different type of classification of energy-efficient VM placement algorithms is done by taking into consideration some relevant criteria.

Criteria Brief Description

Some relevant criteria are considered for classification of VM placement algorithms. Though these criteria are self-understood by their names a brief description of these is given below:

- *Number of Objectives*

Different VM placement algorithms achieve different number of objectives. These algorithms also proved that the proposed objectives were achieved.

- *Objective Function(s)*

The name of the objective function is mentioned in this column out of which energy efficiency is an objective of all the mentioned algorithms because the study was restricted to energy efficient VM placement algorithms.

- *Approach Used*

Here the approach for VM placement is mentioned which states the type either Ant Colony Optimization (ACO), Genetic Approach (GA), First-fit Decreasing (FFD) heuristic, Best-fit Decreasing heuristic, Swarm Intelligence (SI), Fire-Fly Algorithm(FFA),Particle Swarm Optimization (PSO),Integer Linear Programming (ILP) and so on.

- *Architecture*

This criteria was taken based on the work of Atefeh [3] who mentioned a taxonomy of deployment of VM placement algorithms on either single data centers or multiple, geo-distributed data centers. Here architecture specifies the range of deployment of VM placement algorithm.

Pictographically these criteria for classification of energy-efficient VM placement algorithms are stated in *Fig. 1*.

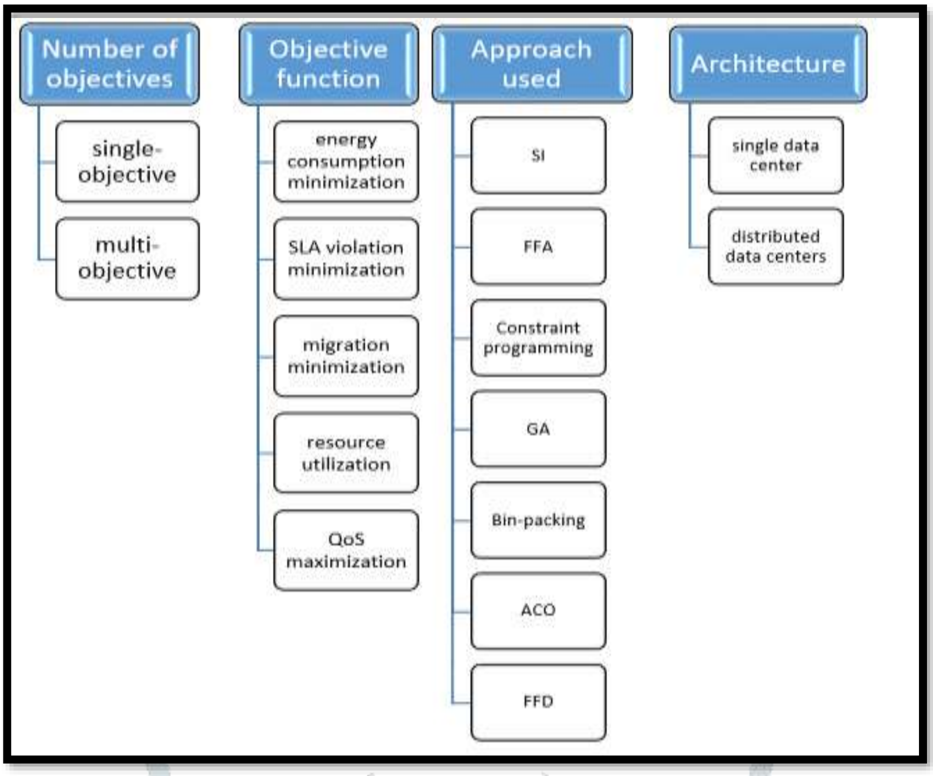

Figure 1: Classification of energy-efficient VM placement algorithms.

Classification results of various energy efficient-VM placement algorithms are given in *Table 1* in which rows specify the name of algorithm and columns specify the criteria used for classification.

Table 1: Multi-criteria classification of energy-efficient VM placement algorithms

Criteria ➡ Algorithm ⬇	**Objective number**	**Objective function(s)**	**Approach used**	**Architecture**	**Comparison in terms of energy efficiency**
VMPACS [7]	Multi-objective	energy efficiency and resource utilization	ACO	Single data center	Better than SACO, MGGA and FFD
RGA-FFD[25]	Multi-objective	energy efficiency and resource utilization	FFD	Single data center	Better than GA-FFD
FGA[16]	Multi-objective	Energy efficiency, migration minimization, minimum SLA violation	GA	Single-data center	Better than THR,LR,LRR,IQR,MAD (existing CloudSim policies)
F1PABFD [14]	Multi-objective	Energy efficiency, migration minimization, minimum SLA violation	BFD, data analysis, forecasting	Single data center	F1PABFD-ARIMA, F1PABFD-ETS, F1PABFD-IDD, F1PABFD-STS, F1PABFD-RW all perform better than aPABFD. F1PABFD-IDD was best.
VMR[23]	Multi-	Energy efficiency, QoS	Bin-packing,	Single data	Better than a random

	objective	aware	threshold	center	algorithm, and two first-fit algorithms FF1 and FF2
GACO-VMP[24]	Multi-objective	Energy efficiency, migrations minimization, resource utilization and resource balance	ACO	Single data center	Better than CompVM and Wrasse
PEVMP[22]	Multi-objective	Energy efficiency, VM execution performance	Auxillary graph, Energy SavingCut function, Greedy Knapsack function	Single data center	Better than EEVMP and LBVMP.
GAPA[13]	Multi-objective	Energy efficiency, resource utilization	GA, Tree	Single data center	Better than BFD
EMHVMP [17]	Multi-objective	Energy efficiency (minimum PMs), resource utilization	Bin-packing, hybrid GA	Single data center	Better than BF and RR
BBO[15]	Multi-objective	Energy efficiency, Minimum computation time	SI	Single data center	Better than GA
IEFWA, and hybrid IEFWA/ BBO[19]	Single-objective	Energy efficiency	SI	Single data center	Better than FFD,BBO,EFWA
HCMFF[21]	Multi-objective	Energy efficiency, minimum SLA violation, minimum migration, less computation time	FFA	Single data center	Better than HB,HCT, and FFA(original)
ECE[12]	Multi-objective	Energy and carbon-efficient, QoS	Constraint programming, Best-fit	Distributed data center	Better than CE-FF,FF-PE,FF-MF,FF-FF
CRA-DP[20]	Multi-objective	Energy and carbon-efficient, QoS	Constraint programming	Geo-distributed data centers	Compared with 6 variations CA-DP, ERA-DP, EA-DP, EA-CP, FD-DP, EPA out of which ERA-DP is best.
ATEA[30]	Multi-objective	Energy efficiency, minimum SLA violation	Bin-packing, BFD	Single data center	Better than IQR-MMT, MAD-MMT,THR-MMT,MIMT and THR-MMT

VMPBPSO [33]	Multi-objective	Energy efficiency and resource utilization	SI (PSO)	Single data center	Better than VMPACS, MGGA, SACO and FFD.
GreenWay [27]	Multi-objective	Energy efficiency and flow performance	Priority based	Single data center	Better than Cluster, Greedy and Random.
PABFD[34]	Multi-objective	Energy efficiency and QoS	BFD	Single data center	--------
Proposed [28]	Multi-objective	Energy efficiency and user price minimization	ILP	Single data center	Better than FFD and EFFD
PHA (offline) and MBF (online)[29]	Multi-objective	Energy efficiency(min. PMs) and execution time minimization	Greedy Best-fit(online),Heuristic(offline)	Single data center	Better than FFD and BFD; Offline better than Online
UBGA[31]	Multi-objective	Energy efficiency and resource utilization	GA	Single data center	Better than RA, CloudSim (default), FFD, VMPGGA
Exact Allocation Algorithm [32]	Multi-objective	Energy efficiency and execution time minimization	Bin-packing and Constraint programming	Single data center	Better than Best-fit algorithm

VII. CONCLUSION

It is evident from the table that most of the algorithms have considered single data center. Only two of them considered energy efficiency in distributed and geo-distributed data centers which are ECE and CRA-DP respectively. Only one of these algorithms i.e. hybrid IEFWA/BBO considered a single objective rest are all multi-objective algorithms. Two algorithms used ACO which are VMPACS and GACO-VMP. One algorithm used FFD which is RGA-FFD and three algorithms used BFD which are F1PABFD, PABFD and ATEA. Four algorithms used genetic algorithms which are FGA, GAPA, UBGA and EMHVMP. Bin-packing approach was used by four algorithms EMHVMP, VMR, ATEA and Exact Allocation Algorithm. One algorithm used priority which is Greenway. Three algorithms used SI approach which are BBO, hybrid-IEFWA/BBO and VMPBPSO. Three algorithms used constraint programming which are ECE, Exact Allocation Algorithm and CRA-DP. FFA approach was used by one algorithm i.e. HCMFF.

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