

AILEC3 - Artificial Intelligence for Lower Energy Consumption in Cloud Computing

Ettore Tancredi Galante
Department of Computer Science
University of Milan
Milan, Italy
ettoretancredi.galante@studenti.unimi.it

I. PRELIMINAR RESEARCH

A. Composite SaaS Placement and Resource Optimization in Cloud Computing Using Evolutionary Algorithms

ANNO: 2012 [14]

Software as a Service (SaaS) is gaining more and more attention from software users and providers recently. This has raised many new challenges to SaaS providers in providing better SaaSes that suit everyone needs at minimum costs. One of the emerging approaches in tackling this challenge is by delivering the SaaS as a composite SaaS. Delivering it in such an approach has a number of benefits, including flexible offering of the SaaS functions and decreased cost of subscription for users.

However, this approach also introduces new problems for SaaS resource management in a Cloud data centre. We present the problem of composite SaaS resource management in Cloud data centre, specifically on its initial placement and resource optimization problems aiming at improving the SaaS performance based on its execution time as well as minimizing the resource usage.

This approach differs from existing literature because it addresses the problems resulting from composite SaaS characteristics, where we focus on the SaaS requirements, constraints and interdependencies. The problems are tackled using evolutionary algorithms. Experimental results demonstrate the efficiency and the scalability of the proposed algorithms.

We have presented the problem of composite SaaS in Cloud data centre, specifically on its initial placement and resource optimization problems. Both problems are formulated as combinatorial optimization problems aiming at improving the SaaS performance based on its execution time as well as minimizing the resource usage. This work differs from all existing research work as it addresses the problems resulting from composite SaaS characteristics, focusing on its requirements, constraints and interdependencies rather than from platform (visualization/hardware) aspects.

We tackled the two combinatorial optimization problems using two different paradigms of evolutionary algorithms. Based on the experimental results, the proposed algorithms always produce a feasible and satisfactory solution to all the test problems. Although the computation time taken is quite

long, it is still acceptable considering that there are various types of maintenance in a data centre that are conducted at different time scales - in term of seconds to hours.

As for our future research work, first, we note that we can improve the implementation of the algorithms to reduce their computation time. The algorithms can be implemented in a parallel manner where the Cloud network can be decomposed into several segments. Second, we plan to investigate on possible integration of solutions for these problems.

Questo lavoro è uno dei più vecchi trovati sull'argomento. È del 2012 ma sottolinea le basi di ciò che è stato sviluppato nei lavori discussi in precedenza.

B. A power efficient genetic algorithm for resource allocation in cloud computing data centers

Anno: 2014 [9]

One of the main challenges in cloud computing is to increase the availability of computational resources, while minimizing system power consumption and operational expenses. This article introduces a power efficient resource allocation algorithm for tasks in cloud computing data centers. The developed approach is based on genetic algorithms which ensure performance and scalability to millions of tasks. Resource allocation is performed taking into account computational and networking requirements of tasks and optimizes task completion time and data center power consumption. The evaluation results, obtained using a dedicated open source genetic multi-objective framework called jMetal show that the developed approach is able to perform the static allocation of a large number of independent tasks on homogeneous single-core servers within the same data center with a quadratic time complexity.

In this paper we introduce a power efficient resource allocation algorithm for cloud computing data centers which is based on genetic heuristics. The proposed approach finds a set of non-dominated solutions in this multi-objective computation minimizing makespan and power consumption of the system. When the execution of the algorithm is completed and optimal Pareto solutions are obtained, it becomes possible to fine tune the trade-off between power consumption and execution time. The proposed algorithm

shows quadratic complexity dependency on with the respect to the number of tasks to be allocated. Future work will focus on model adaptation to dynamic task allocation, account for internal communications, electricity cost and data center load factor and provide comparisons with other state-of-the-art algorithms.

Il paper propone un algoritmo ex novo che sia energeticamente efficiente. L'algoritmo è basato su euristiche genetiche. Problema: ha complessità quadratica.

C. A Survey of Evolutionary Computation for Resource Management of Processing in Cloud Computing [Review Article]

ANNO: 2015 [4]

Cloud computing is significantly reshaping the computing industry. Individuals and small organizations can benefit from using state-of-the-art services and infrastructure, while large companies are attracted by the flexibility and the speed with which they can obtain the services. Service providers compete to offer the most attractive conditions at the lowest prices. However, the environmental impact and legal aspects of cloud solutions pose additional challenges. Indeed, the new cloud-related techniques for resource virtualization and sharing and the corresponding service level agreements call for new optimization models and solutions. It is important for computational intelligence researchers to understand the novelties introduced by cloud computing. The current survey highlights and classifies key research questions, the current state of the art, and open problems.

This survey has presented a wide range of CC problems addressed by all major CI paradigms. CI proves to be applicable to multiple resource management problems that exist at all layers of CC. The advantages of CI paradigms in the field of CC are complementary:

- ANNs can be used to predict workloads;
- FSS may be used to deal with uncertainties;
- EAs may be applied for search and optimization.

CI and CC are in fact cross-fertilizing:

- CI contributes multiple tools that can deal with the dynamics, the uncertainty, the growing scale and multiple objectives of cloud systems;
- CC proposes challenging new problems that lead to the creation and the improvement of CI theory and practice.

As CC proves to be a new major paradigm, with growing market share and research interest, and as CI becomes more widely applied and accepted in real-life (often critical) systems, everything suggests that the connections between CI and CC will expand and strengthen over time.

There is still plenty of room for improvement, exploration, and hybridization of novel approaches to the optimization in the domain of CC. The current state of the art is merely an introduction to the solution of the wide range of novel challenging CC problems. **The most promising are likely to be connected with holistic and cross-layer optimization.**

Due to the multiplicity of involved factors, a multiagent or game theoretic approach may be necessary to coordinate all engaged CI tools.

There are other opportunities for hybridization, such as joining CI with machine learning or mathematical programming: the former for increased adaptability, the latter for accuracy and predictability of results. On the technical side, the CC landscape is continuously evolving, impacting the relevance of the existing problems and the emergence of new ones. Hybrid clouds are prominent examples, using multiple CC deployment models in a single system.

Despite sketching the landscape of CC resource management problems in this survey, **there is still no uniform formal framework that could serve as a precise, simple, and detailed classification of the field.** In conclusion, considering all the new challenging problems, research and development in this field are still in their infancy, and the opportunities for the CI community are manifold.

Per ora il paper più interessante sulla piazza. Spiega molto bene le idee dietro ciascun paradigma. Non parla nello specifico di "risparmio energetico" ma di gestione delle risorse. Comunque interessantissimo.

D. An Appraisal of Meta-Heuristic Resource Allocation Techniques for IaaS Cloud

ANNO: 2016 [7]

This appraisal investigates the meta-heuristics resource allocation techniques for maximizing financial gains and minimizing the financial expenses of cloud users for IaaS in cloud computing environment. A total of 91 studies ranging from 1954 to 2015 have been reviewed.

Out of this set, 23 are selected because they focus on the meta-heuristic algorithms. The selected papers are categorized into eight groups according to the optimization algorithms used. Various issues addressed (optimal and dynamically resource allocation, energy and QoS aware resource allocation, VM allocation and placement) were pointed out through resource allocation meta-heuristics algorithms.

The improvement shows better performances in execution response time, energy consumption and cost. It enhances efficiency and QoS. The comprehensive review and systematic comparison of meta-heuristic resource allocation algorithms described in this appraisal will help researchers to analyze different techniques for future research directions. In this paper, we have reviewed most significant meta-heuristic algorithms for resource allocation in IaaS Cloud. Numerous techniques to enhance the performance of meta-heuristics have been considered in these algorithms. There does not seem to exist a meta-heuristic algorithm better than the others in terms of sheer superiority of performances.

Questo paper sembra molto interessante per le tecniche proposte e i loro paragoni. Posso sceglierne uno e sperimentare su quello.

E. A survey and taxonomy on energy efficient resource allocation techniques for cloud computing systems

ANNO: 2016 [5]

In a cloud computing paradigm, energy efficient allocation of different virtualized ICT resources (servers, storage disks, and networks, and the like) is a complex problem due to the presence of heterogeneous application (e.g., content delivery networks, MapReduce, web applications, and the like) workloads having contentious allocation requirements in terms of ICT resource capacities (e.g., network bandwidth, processing speed, response time, etc.). Several recent papers have tried to address the issue of improving energy efficiency in allocating cloud resources to applications with varying degree of success. However, it doesn't seem to be any published paper on this subject that clearly articulates the research problem and provides research taxonomy for succinct classification of existing techniques. Hence, the main aim of this paper is to identify open challenges associated with energy efficient resource allocation. In this regard, the study, first, outlines the problem and existing hardware and software-based techniques available for this purpose. Furthermore, available techniques already presented in the literature are summarized based on the energy-efficient research dimension taxonomy. The advantages and disadvantages of the existing techniques are comprehensively analyzed against the proposed research dimension taxonomy namely: resource adaption policy, objective function, allocation method, allocation operation, and interoperability. In recent years, energy efficient resource allocation of datacenter resources has evolved as one the critical research issue. We have identified power and energy inefficiencies in hardware and software, and categorized existing techniques in the literature along with the summary of their benefits and limitations. We have discussed the resource allocation problem in general along with associated challenges and issues. Moreover, we discussed the advantages and disadvantages of various resource allocation strategies in literature, and highlighted open issues and future directions.

Paper un po' così, non è utilissimo. Usarlo come reference per altri paper più interessanti.

F. A deep reinforcement learning based framework for power-efficient resource allocation in cloud RANs

ANNO: 2017 [13]

This paper is about *Cloud Radio Access Networks (RANs)* and the improvement of the allocation of resources to minimize power consumption while meeting the demands of wireless users over a long operational period.

A framework based on *Deep Reinforcement Learning* is presented to allocate resources in a power-efficient fashion. Specifically, three spaces are defined:

- State space
- Action space
- Reward function

The reward function is for the DRL agent to apply a Deep NN to approximate the action-value function and formulate

the resource allocation problem for each decision epoch in a convex optimization problem. The simulation results show it can achieve significant power savings while meeting user demands, and it can well handle highly dynamic cases.

Si tratta di un paper che esplora il deep reinforcement learning. Interessante l'approccio presentato, non tratta di algoritmi genetici tuttavia.

G. Evolutionary Algorithms in Cloud Computing from the Perspective of Energy Consumption: A Review

ANNO: 2018 [8]

Cloud Computing provides utility-based IT services. The services are available as pay per use. Cloud gives advantage to organizations in setting up fundamental hardware and software requirements i.e. instead of purchasing hardware or software cloud services can be used. The availability of cloud services any time and anywhere makes it a feasible solution for many applications. cloud services are constrained by some parameters such as Quality of Service (QoS), efficient utilization of cloud resources, user budget, user deadlines, energy consumption etc. In this article, we present a comprehensive review of techniques or algorithms designed to reduce energy consumption in cloud data centers. The review covers Evolutionary Algorithms (EA) such as Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) and Genetic Algorithms (GA). We discuss each technique with strengths and weaknesses. Target objectives of each algorithm are also compared. The article is concluded with future research directions.

In this article, we present a comparative study of different methods based on Evolutionary Algorithms used to reduce energy consumption in cloud computing. A comparative analysis is also presented. Authors in previous works have focused on some parameters, while others are not considered. The developed methods should consider objectives that are related to each other. Improving one objective affects other objectives and makes it difficult to implement. In most of the algorithms, the problem of privacy and security in cloud computing has not been considered while designing scheduling algorithm. Cloud computing is vulnerable to various security attacks and the developed methods should consider this objective as well.

Il paper per ora più recente collegato all'argomento di tesi. Non pare che ce ne sia uno più aggiornato. Raccoglie molti studi ed esperimenti passati. Molto molto utile.

H. A Systematic Review of Energy Management Strategies for Resource Allocation in the Cloud: Clustering, Optimization and Machine Learning

Anno: 2021 [6]

Nowadays, many organizations and individual users are employing cloud services extensively due to their efficiency,

reliability and low cost. A key aspect for cloud data centers is to achieve management methods to reduce energy consumption, increasing the profit and reducing the environmental impact, which is critical in the deployment of leading-edge technologies today such as blockchain and digital finances, IoT, online gaming and video streaming. In this review, various clustering, optimization, and machine learning methods used in cloud resource allocation to increase the energy efficiency and performance are analyzed, compared and classified.

Specifically, on the one hand, we discuss how clustering methods and optimization techniques are widely applied in energy management due to their capacity to provide solutions for energy consumption reduction. On the other hand, we study how multi-objective optimization methods focus on reducing energy consumption as well as service level agreement (SLA) violation, and improving quality of services (QoS) simultaneously. Also, we discuss how optimization methods such as the firefly algorithm, whale optimization algorithm (WOA), particle swarm optimization (PSO) and genetic algorithm (GA) provide the highest performance in the field.

Moreover, we analyze how machine learning methods such as deep neural network (DNN), random forest, and support vector machine (SVM) are applied to the prediction of energy consumption in the cloud, showing an accurate performance in this prediction. Nevertheless, we study how the existing methods still have limitations of low convergence, trap into local optima and overfitting.

In this review, various methods of clustering, optimization, and machine learning methods for the energy management in cloud resource allocation were discussed, and a taxonomy was proposed. As analyzed, on the one hand, most of the clustering methods applied the k-means based method. The k-means based methods have the limitation of random initial cluster that affects the efficiency of the model. On the other hand, optimization methods such as the WOA, firefly algorithm, PSO and GA methods has higher efficiency in terms of energy. Optimization methods have the limitations of the lower convergence and easily trap into local optima.

Machine learning methods such as DNN, SVM, and random forest were applied for the energy consumption prediction and allocate the resource based on the prediction. The DNN method has the limitation of overfitting problem and the SVM method has lower performance in the imbalance dataset. Some of the existing research that displayed higher performance in the energy management employed the WOA, and DNN methods.

Also, the NSGA-II optimization method is highly efficient for multi-objective optimization to optimize the energy consumption. Mostly, the optimization methods have limitations of being trapped in local optima and poor convergence. In the future, statistical methods should be applied to provide a better convergence and to increase the exploration and exploitation of the optimization methods in cloud energy management for

resource allocation.

Probabilmente il paper più rilevante, ed anche il più recente. Mostra come gli algoritmi genetici siano i più performanti in termini di energia.

I. An advanced artificial intelligence technique for resource allocation by investigating and scheduling parallel-distributed request/response handling

Anno: 2021 [3]

Cloud computing is an emerging technology undergoing various challenges that integrate parallel and distributed computing together. In the multi-tenant environment cloud applications can be utilized as a service. User request are enormous and therefore the attributes to be concerned about are scalability, reliability, and resource availability and server response. Utilization of software, platform and infrastructure increases in this environment paving way for resource consumption. This scenario arises various types of issues through collision, traffic jam, data loss, request dropout and delay in response. The past research provides solutions for aspects like scalability, resource allocation, scheduling, load balancing and optimized request and response handling, resource management through virtualization. The process of virtualization and migration of environment is difficult. The cost for allocating VM for a single user is less.

The paper proposed a novel scheduling approach for handling unlimited incoming request with quality of service through energy and throughput. The allocated resource focus on maintaining incoming job request, request for dispatch to the server and an acknowledgement for the receipt of response. The paper provides resource allocation methodology through scheduling approaches called integrating of AI techniques namely Genetic Algorithms (GA) and Artificial Neural Networks (ANN). The property of the request is analyzed and priority is applied for scheduling the request using resource allocation.

The main objective of this paper is to suggest artificial intelligent technique for resource allocation by investigating and scheduling parallel distributed request response handling in cloud environment. A priority value is fixed based on fitness value and jobs are prioritized and arranged in a queue and transferred to resource allocation. Based on fitness value resources are allocated. Jobs are optimized by calculating values of attributes assigned to incoming jobs. For instance the Proposed ANNGA provides 0.5 ms whereas the existing ACO provides 1 ms for 20% of fault detection. Therefore resources are allocated and executed effectively in the proposed method. In the future we will increase the robustness of our algorithms by handling such errors dynamically. In addition, due to this performance degradation error, we will consider SLA negotiation in Cloud computing environments to improve the robustness. We will also add different type of services and other pricing strategies such as spot pricing to increase the profit of service provider. **Alta rilevanza, includere assolutamente.**

J. Multi-objective Virtual Machine Placement in Virtualized Data Center Environments

Anno: 2010 [12]

Server consolidation using virtualization technology has become increasingly important for improving data center efficiency. It enables one physical server to host multiple independent virtual machines (VMs), and the transparent movement of workloads from one server to another. Fine-grained virtual machine resource allocation and reallocation are possible in order to meet the performance targets of applications running on virtual machines. On the other hand, these capabilities create demands on system management, especially for large-scale data centers. In this paper, a two-level control system is proposed to manage the mappings of workloads to VMs and VMs to physical resources. The focus is on the VM placement problem which is posed as a multi-objective optimization problem of simultaneously minimizing total resource wastage, power consumption and thermal dissipation costs. An improved genetic algorithm with fuzzy multi-objective evaluation is proposed for efficiently searching the large solution space and conveniently combining possibly conflicting objectives. A simulation-based evaluation using power-consumption and thermal-dissipation models (learned from profiling of a BladeCenter), demonstrates the good performance, scalability and robustness of our proposed approach when compared with four well-known bin-packing algorithms and two single-objective approaches. Our approach can seek and find solutions that exhibit good balance among the conflicting objectives while others cannot.

Uno dei paper più vecchi che si occupa dell'argomento, citato praticamente da tutti gli altri.

K. Cloud-IoT Resource Management Based on Artificial Intelligence for Energy Reduction

Anno: 2022 [1]

The rapid growth in demand for cloud services has led to the creation of large-scale data centers, which allows application service providers to lease data center capacity for application deployment as per user requirement in terms of quality of services (QoS). These data centers consume a lot of electrical power which contributes to increased operating costs and carbon dioxide emissions. In addition, modern cloud computing environments must provide QoS for their customers which leads them to a need to make a power-performance compromise that is to say in terms of energy consumption and service-level agreement (SLA) compliance.

That is why, we introduce, in this paper, an intelligent resource management policy for cloud data centers. The goal is to dynamically allocate and continuously consolidate virtual machines taking advantage of live migration and disengage inactive nodes to minimize power feeding in this cloud environment while maintaining the quality of service. We integrate some artificial intelligence concepts to ensure a dynamic resource management and a better

power-performance compromise and significantly reduce the consumed energy.

Non usano algoritmi genetici ma Reinforcement Learning. Tuttavia, sembra un po' scarso come articolo. Comunque da tenere in considerazione

L. Artificial Intelligence-Driven Mechanism for Edge Computing-Based Industrial Applications

Anno: 2019 [11]

Due to various limitations i.e., computational complexity and more delay in cloud computing is overtaken by edge computing for efficient and fair resource allocation such as, power and battery lifetime in internet of things (IoT) based industrial applications. In the meantime intelligent and accurate resource management by artificial intelligence (AI) has become the center of attention especially in industrial applications. With the coordination of AI at the edge will remarkably enhance the range and computational speed of IoT based devices in industries. But the challenging issue in these power hungry, short battery lifetime and delay intolerant portable devices is inappropriate and inefficient classical trends of fair resource allotment. Also, it is interpreted through extensive industrial data sets that dynamic wireless channel could not be supported by the typical power saving and battery lifetime techniques for example, predictive transmission power control (PTPC) and Baseline. Thus, this paper proposes i) a forward central dynamic and available approach (FCDA) by adapting the running time of sensing and transmission processes in IoT-based portable devices ii) a system-level battery model by evaluating the energy dissipation in IoT devices iii) a data reliability model for edge artificial intelligence based IoT devices over hybrid TPC and duty-cycle network. Two important cases for instance, static (i.e., product processing) and dynamic (i.e., vibration and fault diagnosis) are introduced for proper monitoring of industrial platform. Experimental test-bed reveals that proposed FCDA enhances energy efficiency and battery lifetime at acceptable reliability (0.95) by appropriately tuning duty-cycle and TPC unlike conventional methods.

Molto interessante e molte citazioni.

M. Cloud and machine learning experiments applied to the energy management in a microgrid cluster

Anno: 2021 [10]

The way to organize the generation, storage, and management of renewable energy and energy consumption features has taken relevance in recent years due to demands that define the social welfare of this century. Like demand increases, other factors require grid infrastructure improvement, updates, and opening to other technologies that assuage the final customer needs. Precisely, the interest in renewable energy sources, the constant evolution of energy storage technologies, the continuous research involving microgrid management systems, and the evolution of cloud computing technologies and machine

learning strategies motivate the development of this article. Tasks associated with a microgrid cluster like the integration of a considerable number of heterogeneous devices, real-time support, information processing, massive storage capabilities, security considerations, and advanced optimization techniques usage could take place in an autonomous and scalable energy management system architecture under a machine learning perspective running in real-time and using Cloud resources. This paper focuses on identifying the elements considered by different authors to define a cloud-based architecture and ensure the appropriately supervised learning functionality under a microgrids cluster environment. Namely, it was necessary to revise and run microgrid simulations, real-time simulation platforms usage, connection to a virtual server for microgrid control and set the energy management system using cloud computing and machine learning. Based on the review and considering the scenarios mentioned, this article presents a scalable and autonomous cloud-based architecture that allows power generation forecast, energy consumption prediction, a real-time energy management system using machine learning techniques.

Qua più per il BG che offre sull'argomento che sulla parte di AI. Sono state usate esclusivamente tecniche di ML, non Ai in generale.

N. Hybridization of firefly and Improved Multi-Objective Particle Swarm Optimization algorithm for energy efficient load balancing in Cloud Computing environments

Anno: 2020 [2]

Load balancing, in Cloud Computing (CC) environment, is defined as the method of splitting workloads and computing properties. It enables the enterprises to manage workload demands or application demands by distributing the resources among computers, networks or servers. In this research article, a new load balancing algorithm is proposed as a hybrid of firefly and Improved Multi-Objective Particle Swarm Optimization (IMPSO) technique, abbreviated as FIMPSO. This technique deploys Firefly (FF) algorithm to minimize the search space where as the IMPSO technique is implemented to identify the enhanced response. The IMPSO algorithm works by selecting the global best (gbest) particle with a small distance of point to a line. With the application of minimum distance from a point to a line, the gbest particle candidates could be elected. The proposed FIMPSO algorithm achieved effective average load for making and enhanced the essential measures like proper resource usage and response time of the tasks. The simulation outcome showed that the proposed FIMPSO model exhibited an effective performance when compared with other methods. From the simulation outcome, it is understood that the FIMPSO algorithm yielded an effective result with the least average response time of 13.58ms, maximum CPU utilization of 98%, memory utilization of 93%, reliability of 67% and throughput of 72% along with a make span of 148, which was superior to all the other compared methods.

Paper interessante e con un discreto numero di citazioni nonostante sia molto recente. È il primo che incontro che propone uno algoritmo di swarm optimization.

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