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It is certified that the work contained in this thesis entitled ”Energy-Aware Scheduling of Workflow Tasks and Consolidation of Virtual Machines in Clouds” by ”Medara Rambabu” has been carried out under my supervision and that it has not been submitted elsewhere for a degree.

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I, Medara Rambabu, certify that the work embodied in this thesis is my own bonafide work and carried out by me under the supervision of Dr. Ravi Shankar Singh from July-2018 to November 10, 2021, at the Department of Computer Science and Engineering, Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any other's work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports dissertations, theses, etc., or available at websites and have not included them in this thesis and have not cited as my own work.

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PREFACE

The rising demand for cloud services witnesses massive expansions in cloud data center infrastructure globally. This unprecedented increase of cloud data centers results in high energy consumption and carbon emissions into the environment. Due to the excessive energy consumption of data centers, there has been a need for developing energy-efficient approaches in the clouds to minimize energy utilization. Cloud service providers have been practicing various energy management strategies to reduce energy consumption to maximize Return On Investment (ROI) and to improve the environment.

This thesis investigates energy-aware workflow task scheduling and Virtual Machine (VM) consolidation techniques in Infrastructure as a service (IaaS) clouds. The scientific workflows with precedence constrained tasks are high-level complex applications that demand high computing power and takes a long time to complete execution. As consequence, cloud data centers consume more electrical energy. The scheduling algorithms efficiently manage cloud resources (VMs) while executing workflow applications to minimize power utilization. The VM consolidation reduces the number of physical servers by switching off the idle machines and consolidate VMs for load balancing. It uses live VM migrations while executing the tasks so that underloaded physical servers can be switched off by migrating all VMs running on it to a normally loaded server(s). The VM consolidation in the cloud environment is a well-known NP-hard problem.

Workflow scheduling and VM consolidation techniques presented in this thesis address fundamental challenges that arise from the multi-tenant, resource-abundant, and elastic resource model and are competent in satisfying a set of Quality-of-Service (QoS) requirements.

The major contributions of this thesis to advances in energy-aware workflow scheduling and VM consolidation as follows:

- A review of the energy-aware workflow scheduling algorithms for IaaS clouds.
- A heuristic-based energy-efficient and cost-aware scheduling algorithm with deadline constraints.
- A heuristic-based scheduling algorithm for energy and reliability optimization.
- A meta-heuristic-based virtual machine consolidation algorithm.
- A hybrid scheduling algorithm with virtual machine consolidation.

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- Medara Rambabu

Contents

List of Figures

List of Tables

Symbols

Bw	bandwidth
DAG	directed acyclic graph
e_{ij}	an edge between tasks i and j
$E-Total$	overall energy consumption
$E(f_{op}^{i.k})$	energy consumption of t_i on vm_k
$EST(t_i)$	earliest start time of t_i
$EFT(t_i)$	earliest finish time of t_i
f	clock frequency
f_{op}^{i}	operating frequency of vm_k
f_{max}^{i}	maximum frequency of vm_k
h_{mips}^{i}	Computing capacity of PM_i
$LST(t_i)$	latest start time of t_i
$minT_M$	minimum makespan
P_{static}	static power
$P_{dynamic}$	dynamic power
P_{ind}	frequency independent power
PM	set of physical machines
pm_{under}	under utilized pm
pm_{over}	overloaded pm
pm_{normal}	normal load pm
P_s	set of sleeping PMs
P_{util}	Power utililization
$P_{CPU_{idle}}$	CPU power utilization at 0% load
$P_{CPU_{full}}$	CPU power utilization at 100% load
$R(f_{op}^{i.k})$	reliability of task t_i

R_W	system reliability
t_{entry}	Entry task
t_{exit}	Exit task
T_D	deadline
T_M	makespan
$\overline{T}(t_i)$	mean execution times of t_i on different available VMs
$T(t_{ij}$	communication time between tasks i and j
$T(t_i, vm_k)$	effective execution time of t_i on vm_k
$Util(vm_k)$	resources utilization of vm_k
vm_k	k th virtual machine
$vm_{mips}^{i,j}$	Computing capacity of vm_j on PM_i
T_w	Set of workflow tasks
W	workflow
$W(c_{ij}$	data transferred from task i to j
h	wave height
λ	wave length
λ_{max}	maximum wave length
α	wavelength reduction coefficient