Problem Formulation: Optimization of Energy Efficiency and Execution Time in Cloud Computing

Roger Bukuru

August 14, 2024

Introduction

This document outlines the problem formulation for optimizing energy efficiency and execution time in a cloud computing environment using various optimization techniques. The objective is to develop models that minimize energy consumption and execution time by applying Mixed Integer Linear Programming (MILP), Simulated Annealing (SA), Genetic Algorithms (GA), and Multi-Objective Goal Programming (MOGP).

Problem Statement

Objective: To minimize energy consumption and execution time in a cloud computing environment.

Key Features:

- CPU usage
- Memory usage
- Network traffic
- Power consumption
- Number of executed instructions
- Execution time
- Task type, priority, and status

Mixed Integer Linear Programming (MILP) Formulation

Objective: Minimize the total cost of energy consumption and execution time.

Decision Variables:

- x_{it}: Binary variable indicating whether task i is scheduled to run at time t.
- r_{ij}: Continuous variable representing the amount of resource j allocated to task i.

Parameters:

- $R_j^{\max}$: Maximum available amount of resource j.
- α, β: Weights assigned to energy consumption and execution time in the objective function.

Objective Function:

$$\text{Minimize } Z = \alpha \times \text{Energy Consumption} + \beta \times \text{Execution Time}$$

Subject to:

$$\text{Resource Constraints: } \sum_i r_{ij} \times x_{it} \leq R_j^{\max}, \quad \forall j, t$$

$$\text{Task Completion Constraints: } \sum_t x_{it} = 1, \quad \forall i$$

Binary Constraints on decision variables.

Simulated Annealing (SA) Approach

Objective: Iteratively minimize energy consumption and execution time by exploring different configurations.

Parameters:

- S: Current solution.
- T: Temperature parameter controlling acceptance of worse solutions.
- ΔE: Change in cost between current and new solution.

Steps:

1. Start with an initial solution S and initial temperature T.
2. For each iteration, generate a new solution S' in the neighborhood of S.
3. Compute the change in cost $\Delta E = E(S') - E(S)$.
4. If $\Delta E < 0$, accept S'. Else, accept S' with probability $\exp(-\Delta E/T)$.
5. Decrease the temperature T and repeat until convergence.

Genetic Algorithms (GA) Approach

Objective: Evolve task allocation strategies to minimize energy consumption and optimize execution time.

Parameters:

- $f(\text{chromosome})$: Fitness function evaluating energy consumption and execution time.
- w_1, w_2: Weights for energy consumption and execution time in the fitness function.

Steps:

1. Initialize a population of chromosomes (task allocations).
2. Evaluate fitness: $f(\text{chromosome}) = w_1 \times \text{Energy Consumption} + w_2 \times \text{Execution Time}$.
3. Selection: Choose the fittest chromosomes.
4. Crossover: Create offspring by combining pairs of chromosomes.
5. Mutation: Introduce small changes to chromosomes.
6. Repeat until convergence or maximum iterations.

Multi-Objective Goal Programming (MOGP) Formulation

Objective: Balance multiple goals like minimizing energy consumption and execution time.

Parameters:

- G_1: Goal to minimize energy consumption.
- G_2: Goal to minimize execution time.
- d^+, d^-: Deviation variables for each goal.
- w_1, w_2: Weights for deviations in the objective function.

Formulation:

1. Define Goals: G_1 - Minimize Energy, G_2 - Minimize Execution Time.
2. Formulate deviation variables (d^+ and d^-) for each goal.
3. Minimize the weighted sum of deviations: Minimize $Z = w_1 \times d_1^+ + w_2 \times d_2^-$.
4. Subject to: Goal constraints, resource constraints.