A Parallel Bi-objective Hybrid Genetic Algorithm to Minimize Energy Consumption and Makespan Using Dynamic Voltage Scaling

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1 Introduction

Precedence-constrained parallel applications are one of the most typical application models used in scientific and engineering fields. Such applications can be deployed on homogeneous or heterogeneous systems. Only recently that some works were interested in minimizing the energy consumption. Various techniques including dynamic voltage scaling (DVS), resource hibernation, and memory optimizations have been investigated and developed. DVS among these has been proven to be a very promising technique with its demonstrated capability for energy savings. For this reason, we adopt this technique and it is of particular interest to this study.

In this paper, we investigated the energy issue in task scheduling particularly on high-performance computing systems (HCSs). We propose a new parallel island-based bi-objective hybrid algorithm that takes into account, not only makespan, but also energy consumption.

The remainder of the paper is organized as follows. Section 2 describes the related work. Our algorithm is presented in Section 3. The results of our comparative evaluation study are discussed in Section 4. The conclusion is drawn in Section 5.

2 Related work

Due to the NP-hard nature of the task scheduling problem in general cases [3], heuristics, in particular meta-heuristics, are the most popularly adopted scheduling model. List scheduling heuristics are the dominant heuristic models. This is because empirically, list scheduling algorithms tend to produce competitive solutions with lower time complexity compared to algorithms in the other categories [5].

The HEFT algorithm [6] is highly competitive in that it generates a schedule length comparable to other scheduling algorithms, with a low time complexity ($O(nlogn + (e + n)p)$). The DBUS algorithm [1] is a duplication-based scheduling heuristic that first performs a critical path based listing for tasks and schedules them with both task duplication and insertion.

The incorporation of energy consumption into task scheduling adds another layer of complexity to an already intricate problem. For this reason, energy-conscious scheduling heuristic (ECS) [2] is devised with relative superiority (RS) as a novel objective function, which takes into account these two performance considerations.

Results clearly demonstrate the superior performance of ECS over DBUS and HEFT. Note that, in many previous studies like [4], HEFT has been proven to perform very competitively, and it has been frequently adopted and extended. However, ECS returns one solution as a result, and precedence-constrained applications problem is bi-objective in nature.

3 A parallel bi-objective hybrid approach

This approach is a hybrid between a multi-objective parallel genetic algorithm and energy-conscious scheduling heuristic (ECS) [2]. Our algorithm is powerful as it profits from the cooperative approach of the island model, the parallelism of the multi-start model, the exploration power of the genetic algorithm, and the intensification capability of the ECS. The island model and the hybridization improve the quality of the obtained results. The multi-start model reduces the running time of a resolution.

– **Hybrid approach:** Our proposed new approach is based on ECS and provides a set of Pareto solutions. This approach is a hybrid between a multi-objective GA and ECS. The role of the GA is to provide good task schedulings. ECS completes the processor and voltage parts of the genes of the partial solutions provided by the GA.
– **Insular approach:** The island model is inspired by behaviors observed in the ecological niches. In this model, several evolutionary algorithms are deployed to evolve simultaneously various populations of solutions, often called islands. The GAs of our hybrid approach asynchronously exchange solutions. This exchange aims at delaying the convergence of the evolutionary process and to explore more zones in the solution space. For each island, a migration operator intervenes at the end of each generation.
– **Multi-start approach:** Compared to the GA, ECS is more costly in CPU time. The different evaluations of ECS are independent of each other. Therefore, their parallel execution can make the approach faster. The objective of the hybrid approach is to improve the quality of solutions. The island approach also aims to obtain better solutions. While the goal of the parallel multi-start approach is to reduce the execution time.

4 Experimental results

Our new approach has been evaluated with the fast Fourier transformation task graph which is a real-world application. Experiments show that our bi-objective meta-heuristic improves, on average, the results obtained in the literature, particularly in energy saving. Indeed, the energy consumption is reduced by **47.49%** and the completion time by **12.05%**. The experiments of the insular approach also show that the more the number of islands is used, the better the results will be. The use of 50 islands, instead of 1 island (i.e. the hybrid approach), improves the S-metric of the obtained Pareto front by **26%**. Furthermore, the multi-start approach is on average **13.06** times faster than the island approach when using 21 cores. The multi-start and insular approaches give the same result (i.e. Pareto front).

5 Conclusions

In this paper, we investigated the precedence-constrained parallel applications particularly on high-performance computing systems. Precedence-constrained parallel applications are deployed mostly with the sole goal of minimizing completion time without paying much attention to energy consumption. We presented a new parallel bi-objective hybrid genetic algorithm to solve this problem which significantly improves the results obtained in the literature. The algorithm minimizes energy consumption and makespan. The energy saving of our approach exploits the dynamic voltage scaling (DVS) technique—a recent advance in processor design.

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