Expert Systems With Applications 67 (2017) 304–311

Contents lists available at ScienceDirect

Expert Systems With Applications

journal homepage: www.elsevier.com/locate/eswa

An improvement on the Migrating Birds Optimization with a problem-specific neighboring function for the multi-objective task allocation problem

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A R T I C L E I N F O

Article history:
Received 11 February 2016
Revised 1 September 2016
Accepted 22 September 2016
Available online 1 October 2016

Keywords:
Distributed systems
Task allocation problem
Metaheuristic optimization algorithms
Stochastic search algorithms

A B S T R A C T

Allocating tasks to processors is a well-known NP-Hard problem in distributed computing systems. Due to the lack of practicable exact solutions, it has been attracted by the researchers working on heuristic-based suboptimal search algorithms. With the recent inclusion of multiple objectives such as minimizing the cost, maximizing the throughput and maximizing the reliability, the problem gets even more complex and an efficient approximate method becomes more valuable. In this work, I propose a new solution for the multi-objective task allocation problem. My solution consists in designing a problem-specific neighboring function for an existing metaheuristic algorithm that is proven to be successful in quadratic assignment problems. The neighboring function, namely greedy reassignment with maximum release (GR-MR), provides a dynamic mechanism to switch the preference of the search between the exploration and exploitation. The experiments validate both that the quality of the solutions are close to the optimal and the proposed method performs significantly better comparing to three other metaheuristic algorithms. Neighboring functions being the common reusable components of metaheuristic algorithms, GR-MR can also be utilized by other metaheuristic-based solutions in the future.

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1. Introduction

Heterogeneous distributed systems yield high performance for computation-intensive parallel and distributed applications with their many processors interconnected via high-speed communication channels. The efficiency of executing an application on those systems depends on the task allocation method used to assign tasks comprising the application onto the processors in the system. Albeit many other criteria, system performance and reliability are the two most common efficiency measures for distributed systems (Attiya & Hamam, 2006; Duman, Uysal, & Alkaya, 2012; Kang, He, & Deng, 1997; Lin, Ying, & Huang, 2013; Pan & Dong, 2014; Pendharkar, 2015; Salman, Ahmad, & Al-Madani, 2002; Shatz, Wang, & Goto, 1992; Yin, Yu, Wang, & Wang, 2007). While the system performance plays an important role in the execution of real-time applications on distributed systems, the system reliability becomes a crucial concern due to high machine and network failure rates in large scale systems (Shatz et al., 1992). Especially, safety-critical systems such as power plants must consider reliability issues as well as performance requirements.

There have been many studies solving the task allocation problem (TAP) in the literature starting with the work of Stone (Stone, 1977). While some methods target performance optimization by minimizing the sum of execution and communication times (Chen & Lin, 2000; Ernst, Jiang, & Krishnamoorthy, 2006; Hansen & Giauque, 1986), or consider system reliability by minimizing the probability of failure (Attiya & Hamam, 2006; Kang, He, Song, & Deng, 2010; Kartik & Murthy, 1997; Shatz et al., 1992), some of them deal with both objectives solving the multi-objective task allocation problem (Kang et al., 1997; Lin et al., 2013; Pendharkar, 2015; Yin et al., 2007). Since the problems with both objectives are NP-hard, many suboptimal heuristic algorithms proposed, as well as exact solutions based on mathematical approaches have been developed to solve smaller problems in reasonable time (Ernst et al., 2006).

Halloway, Lan, and Kemal (1980) proposed some heuristic methods to minimize the communication cost between processors. They used control flow graphs to estimate inter module communication and grouped with the highest communicating tasks within the same processor which they named as fusion. Shatz et al. (1992) stated a formal definition of task allocation problem for maximizing the system reliability as a quadratic assignment problem. With the only objective of maximizing reliabil-

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http://dx.doi.org/10.1016/j.eswa.2016.09.035
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ity, they offered an A∗-based optimal algorithm for small systems and a suboptimal algorithm for more realistic systems.

Use of evolutionary metaheuristic optimization algorithms and stochastic search algorithms are also popular for the task allocation problem. Genetic algorithm was proposed by Hadj-Alouane (1996); Vidyarthi and Tripathi (2001), for maximizing the reliability of distributed computing systems. For the same objective, Attiya and Hamam (2006) adapted a simulated annealing approach. They defined a problem-specific energy function which they considered as the heart of simulated annealing algorithm. Random switching of a task from one processor to another was used as neighboring function. They compared the algorithm performance with an optimal branch and bound (BB) technique and showed that SA gave near optimal results for most of the cases. Multi-objective task allocation problem was tackled by the study of Yin et al. (2007), in which, they proposed a hybrid particle swarm optimization method. In their formulated problem the objective function consists of both performance cost and reliability cost functions. A modification of harmony search algorithm is proposed by Zou, Gao, Li, Wu, and Wang (2010) to minimize the communication cost. Honey bee mating algorithm was used by some other studies for the assignment of tasks with different objectives (Kang, He, & Deng, 2012; Kang et al., 2010; Mirzazadeh, Shirdel, & Masoumi, 2011). Duman et al. (2012) adapted their own metaheuristic optimization algorithm, namely Migrating Bird Optimization (MBO), to quadratic assumption problem and achieved promising results. The proposed method was further improved by Pan and Dong (2014) with problem specific neighboring heuristics. Recently, Pendharkar (2015) proposed an ant colony optimization adaptation to task allocation problem in which he tried to minimize the overall execution cost and the inter task communication cost.

The attempt to minimize the communication cost in solving task allocation problem was also made by Yadav, Singh, and Sharma (2011), by allocating the same processor for heavily communicating tasks. They used a heuristic metric, which they named as communication links sum, a summation over the communication costs of the tasks. The allocation of tasks to processors were performed according to CLS values of tasks in a greedy manner. Similarly, an iterative greedy algorithm for task allocation problem was presented by Kang, He, and Wei (2013). Instead of minimizing the communication cost, their objective was maximizing the reliability of the distributed system.

In this paper, I present an improvement for the MBO algorithm, which is a recent metaheuristic optimization algorithm that is shown to achieve successful performance in quadratic assignment problems (Duman et al., 2012; Pan & Dong, 2014). My main contribution is introducing a novel neighboring function designed specifically for multi objective task allocation problem. The proposed algorithm yields significantly better results in terms of solution quality.

The remainder of this paper is organized as follows: Firstly, a general description and a formal definition of the multi objective task allocation problem, that is undertaken in this study, are presented. Then I describe the basic MBO algorithm and the proposed improvement with the problem-specific neighboring function, which is followed by the experimental study. Finally, I will summarize the work with some conclusive remarks.

2. Task allocation problem

In this work, I consider multi objective task allocation problem that aims allocating tasks of a parallel application onto processors of a distributed system with the goal of minimizing the system cost and maximizing the system reliability. I use the problem statement given in (Attiya & Hamam, 2006; Kang et al., 2012; Yin et al., 2007) to formulate the task allocation problem.

2.1. System model

I consider a heterogeneous distributed computing system with N processors $(P_1, P_2, \ldots, P_N)$ connected by an interconnection network and a parallel application running on this system with K tasks $(T_1, T_2, \ldots, T_K)$, as shown in Fig. 1.

Each processor P_n has the following attributes:

- C_n: the available processing capacity
- M_n: the available memory capacity
- λ_n: the failure rate

There is a communication link between different processors. The communication path between two processors (P_n, P_m) has the following attributes:

- DTR_{nm}: the data transfer rate between processors
- μ_{nm}: the failure rate of the communication path between processors

Each task T_k has the following attributes:

- c_k: the processing load demand
- m_k: the amount of memory required

Each task pair (T_k, T_l) may communicate each other with an amount of data, and this inter-task communication can be characterized as follows:

- D_{kl}: the amount of data to be transferred between tasks

A task may take different execution time if it is executed on different processors. ET_{kn} represents the expected execution time of a task T_k on the processor P_n, for each task and processor pair.

The aim is to find a task allocation represented by X, the assignment of K tasks onto N processors, that minimizes the system cost and maximizes the system reliability simultaneously while satisfying memory and computation resource constraints, where $X_{kn} = 1$ if task T_k is assigned to processor P_n and $X_{kn} = 0$ otherwise.

2.2. System cost

As the performance of the target system, I consider the system cost, which is defined as the sum of execution and communication times. Given a task allocation X, since the execution time of all tasks in processor P_n is $\sum_{k=1}^{K} X_{kn} ET_{kn}$, the total execution time of all processors can be computed as follows:

$$C_{exec}(X) = \sum_{n=1}^{N}\sum_{k=1}^{K} X_{kn} ET_{kn}$$

Similarly, since the total time for task communications between processors P_n and P_m is $\sum_{k=1}^{K-1}\sum_{l=k+1}^{K} X_{kn} X_{lm} (D_{kl}/DTR_{nm})$, the total communication time of all processors can be computed as follows:

$$C_{comm}(X) = \sum_{n=1}^{N-1}\sum_{m>n}\sum_{k=1}^{K-1}\sum_{l=k+1}^{K} X_{kn} X_{lm} (D_{kl}/DTR_{nm})$$

Then the system cost for a task allocation X can be computed as follows:

$$\mathbf{C(X)} = C_{exec}(X) + C_{comm}(X) \tag{1}$$

$$= \sum_{n=1}^{N}\sum_{k=1}^{K} X_{kn} ET_{kn} + \sum_{n=1}^{N-1}\sum_{m>n}\sum_{k=1}^{K-1}\sum_{l=k+1}^{K} X_{kn} X_{lm} (D_{kl}/DTR_{nm})$$

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