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A metaheuristic algorithm to solve satellite broadcast scheduling problem

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A B S T R A C T

In this paper a new effective and scalable differential evolution algorithm is proposed for optimizing the Satellite Broadcast's Scheduling problem (SBS). The satellite broadcast's scheduling optimization problem is known to be an NP-complete problem in which the aim is to find a valid broadcasting pattern to earth-stationed terminals which maximizes the number of timeslots utilized for broadcasting under certain constraints. The algorithm proposed SD-BDE, is a binary version of Differential Evolution hybridized with ideas extracted from Stochastic Diffusion search. On top of that a repair heuristic mechanism is added to resolve constraint violations. Preliminary analysis shows that the repair heuristic is very effective as compared to other versions which include other heuristics. Further, the performance of the proposed algorithm is tested thoroughly against published work toward solving SBS problem as well as state-of-the-art existing binary-coded population-based similar algorithms. In this paper, we used, along with instances reported in the literature for such problem, randomly generated benchmark's instances of varying sizes for the sake of creating a unified large-scale set to compare different algorithm against. Experimental results show that the proposed algorithm outperformed the existing algorithms by finding better or optimal solutions for almost all tested benchmarks.

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1. Introduction

Multi-billion dollar satellite communications technology have refined our world by playing a key role in creating a global culture, spreading worldwide entertainment, stimulating technological interchange, and promoting trade around the world [18,29]. Because of an explosive growth of essential applications, there is an increase in number of satellites systems. A satellite communication system is characterized by the number of satellites orbiting the earth at high-altitude or low-altitude, a number of stationary ground terminals on the earth and a number of communication requests, one for each satellite specifying how long the satellite must broadcast in order for the communication task to be executed [19]. Some of the potential advantages of low-altitude satellites include: reduced satellite power requirement and portable antennas, smaller propagation delays, high resolution images and cheaper to launch than satellites at higher geosynchronous altitude. Since, the low-altitude satellites are not always visible from the ground terminals, a handover between satellites is necessary in order

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for communications requests to be satisfied. This handover constitutes the satellite broadcast scheduling (SBS) problem for low-altitude satellite communication systems. Hence, the optimization of the broadcasting time from a set of satellites to a set of ground terminals has emerged as an important design problem in satellite communication systems. The satellite broadcast scheduling optimization problem is known to be an NP-complete problem [1,21]. The goal of SBS is to find the valid broadcasting scheduling pattern which maximizes the number of broadcasting timeslots under some set of constraints. Based on domain specific constraints, the term satellite scheduling has been applied to different aspects of satellite operations, such as remote sensing and communications operations, for which constrained based solutions have been proposed [2,3]. However, the satellite broadcast scheduling addressed in this paper is different since it does not address the peculiarities of the satellite scheduling problem, such as including renewable and alternative resources and/or preemptive tasks. Similarly, the addressed problem is different from the broadcast scheduling problem in wireless networks to effectively harness the shared radio channel bandwidth by avoiding both direct and hidden message collisions [24]. The problem is an example that can be mapped into other similar satellite communication optimization problems. Solving the problem will open avenue for solving those similar problems.

A number of approaches with varying degree of success have been applied for solving the broadcast scheduling problem in satellite communication systems [1–7]. Bourret et al. [4,5] solved the problem by using a neural network in which neurons are connected in a three-layer model. A sequential search, which is controlled by a competitive activation mechanism based on dynamic prioritization of satellites, was used to find the optimum solution. The sequential search is local in scope and is very time consuming. Moreover, the dynamic distinct priority of satellites is difficult to determine, which is needed by their technique. Ansari et al. [1] applied mean field annealing technique (MFT), which is based on Hopfield Neural Network and all neurons are completely connected, in combination with the mean field annealing theory. MFT reported better results as compared with [4,5]. However, it requires calculating exponent term to update the state of neurons, which is compute-intensive. Moreover, number of iteration steps for the convergence rapidly increases with the problem size. Funabiki and Nishikawa [10] proposed a simple binary neural model which searches for the global solution first. If it cannot find the global solution, then it will search for the local solution. A parallel artificial neural network technique reported in [25] decomposed the neural network into sub-networks, which are coordinated by employing lateral inhibition. No results were reported in their paper. Shen and Wang [21] solved the broadcast scheduling problem by using Competitive Hopfield Neural Network model which differs from the original Hopfield Network in that a competitive winner-take-all mechanisms is imposed. The competitive learning rule provide a highly effective means of gaining solution and reduce the time-consuming task of obtaining system coefficients. Li et al. [13] applied genetic algorithms to solve the problem. They developed genetic operator to improve the convergence. However, the optimum choice of parameters takes long computation time.

Recently, Chen et al. [6,7] presented a low complexity algorithmic framework based on the modeling and computation methodology of factor graphs to solve the satellite broadcasting problem. However, the approach was tested only on problems of small size (4 satellites, three ground terminals and 9 slots). Therefore, it is difficult to judge the effectiveness of their approach on problems of large size. Some of the shortcomings of the existing techniques are that either they are slow or converge to a local optima. An approach based on the particle swarm optimization (PSO) algorithm was proposed by Xia et al. [30]. In their approach Xia et al. [30] introduced an optimal objective function that should minimize the difference between the number of timeslots in the solution and the required number of timeslots. In Xia et al. [30] model the system should not assign periods more than the required number. Again, the PSO approach was tested only on problems of small size (4 satellites, three ground terminals and 9 slots), so it is difficult to judge its effectiveness.

Since the satellite broadcast scheduling problem is an NP-complete [1,10,25,13,21], a good exact algorithm for its optimal solution in polynomial time is unlikely to exist. Therefore, optimal solution strategies must be sacrificed in favor of fast heuristic techniques. Because of the intractable nature of the stated problem and its importance in satellite communications, it is highly desirable to explore other avenues for developing good heuristic algorithms for the problem.

In this paper, we proposed a new fast and scalable algorithm based on the meta-heuristic Stochastic Diffusion search method hybridized with Differential Evolution (i.e. SD-BDE). As will be shown in next sections, the results show that the developed SD-BDE algorithm is a promising optimization method. The remainder of the paper is organized in the following manner. Summary of the broadcast scheduling problem is given in Section 2, whereas Section 3 overviews Differential Evolution algorithm. The implementation of our proposed algorithm to solve the broadcast scheduling problem is described in Section 4. Experimental results on benchmark problems and comparison to similar, state-of-the-art methods are reported in Section 5. Finally, Section 6 concludes the paper.

2. Broadcast scheduling problem formulation

The problem definition of this paper basically follows [4,5,1,10,25]. Let us consider a satellite broadcasting systems consisting of I ground terminals $(1 \leqslant i \leqslant I)$, J satellites $(1 \leqslant j \leqslant J)$, and K timeslots $(1 \leqslant k \leqslant K)$. The communication links between the satellites and ground terminals are provided in a repetition of timeslots. A timeslot has a unit time to broadcast information from a satellite to a terminal or from terminal to a satellite when they are visible to each other. A set of requests for broadcasting time of satellites is given by the request vector $R, R = [r_1, r_2, r_3, \ldots, r_J]$, where J represents the

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