Research on spectrum scheduling based on discrete artificial bee colony algorithm

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Abstract. With the increasing shortage of spectrum resources on the earth, how to ensure the high-quality transmission of satellite wireless signals to the ground has become one of the most important problems in the current satellite ground communication system. In order to schedule spectrum resources more reasonably and efficiently, we propose a spectrum resource scheduling model based on adaptive chaotic distributed differential artificial bee colony algorithm. The algorithm uses chaotic distribution to generate initial solution. In the search phase, differential evolution strategy and artificial bee colony algorithm are used to work in parallel to find the local optimal solution. The selection operator is used to calculate the probability of selecting new bee sources, which improves the reliability and convergence speed of the algorithm. Finally, the results show that in single-channel and multi-channel scenes, the algorithm can help to improve the fairness and throughput.

1. Introduction

Due to the increasing demand for the security, real-time and high-speed of satellite system business, the satellite system needs to make continuous progress in the overall architecture and related technical support to meet people's high standards and strict requirements. The traditional spectrum scheduling method cannot use the idle frequency band effectively which make the spectrum resources increasingly tense [1]. The introduction of wireless spectrum resource scheduling method in satellite system can effectively improve the utilization of spectrum resources and achieve fair allocation of spectrum resources.

Aiming at the problem that the spectrum scheduling model can’t balance the fairness and throughput well, this paper proposes a spectrum scheduling algorithm based on adaptive chaotic distribution differential artificial bee colony. The algorithm takes into account the interference in the process of satellite signal transmission, the location of the ground station and the receiving ship, and the interference between the receiving equipment. Using artificial bee colony algorithm to calculate the priority can adaptively change the scheduling path, effectively search the optimal scheduling path. Based on the effective capacity [2], the spectrum scheduling methods of one to many in single-channel and many to many in multi-channel are proposed [3]. Fairness and throughput based on perception time [4] are used to verify the effectiveness of the algorithm.

2. Materials and Methods

2.1. Improvement of artificial bee colony algorithm
Artificial bee colony algorithm (ABC) is an algorithm inspired by karaboga group to optimize modern problems. It is a specific application of the idea of cluster intelligence [5]. The algorithm has fast convergence, simple parameter setting and good results [6]. However, the algorithm has some disadvantages, such as weak local search ability, easy to fall into local optimal solution, premature convergence, redundant calculation and so on. In this paper, a differential artificial bee colony algorithm based on adaptive chaotic distribution is proposed. Firstly, the bee colony is initialized with chaotic sequence. Then, the artificial bee colony algorithm and differential evolution algorithm are used to find the local optimal solution. Finally, the RK discrete algorithm is used to find the near honey source.

Population initialization: Population initialization is directly related to the convergence of the algorithm. We use the chaos formula to produce random values, which can make the distribution of initial solutions more representative. As shown in formula (1).

$$x_{id} = \mu x_{id}(1 - x_{id})$$  \hspace{1cm} (1)

Among them, $x_{id}$ is the d-dimensional solution of the i-th food source. $\mu \in [0,4]$ is called logistic parameter. In this chapter, $\mu$ is set to 4, which is completely chaotic.

Search strategy: In the traditional artificial bee colony algorithm, the feasible solution is obtained by the offset of another random individual. In this paper, differential evolution algorithm is used to improve the traditional ABC algorithm. NP feasible solutions are randomly generated and randomly divided into two groups. Differential evolution algorithm and artificial bee colony are used to calculate respectively, and the optimal solution is obtained by comparing them. When searching for the optimal solution near the honey source, all the colonies are combined and divided into two groups again. Each iteration uses two groups of algorithms to compare and select the local optimal solution, and finally produces the optimal solution.

Common differential evolution strategies [7]: De/best/1, De/RAND/1, De/best/2, De/RAND/2. In this paper, De/best/1 is used, as shown in formula (2).

$$v_{ij} = x_{best,j} + F(x_{k1,j} - x_{k2,j})$$  \hspace{1cm} (2)

Here, $x_{best,j}$ is the most individual of the current population, $j \in (1,2, ..., D)$ is a random integer, $k_1, k_2 \in \{1,2, ..., SN\}$, is a random integer and $k_1 \neq k_2 \neq i$, $F \in (0,2)$ represents the difference factor, which is used to control the amplification of deviation.

Adaptive adjustment: We use RK method to adjust the optimization algorithm. The continuous optimization algorithm is extended to the integer combinatorial optimization problem. The randomly generated solutions are mapped back to the solution space. The principle is to randomly generate a group of solutions and arrange the newly calculated solutions in ascending order. The obtained array is given integer values in order. For example, if the randomly generated solution vector $X = (3.5,6.4,0.3,1.8,2.1)$, then the solution obtained after RK discretization is $X = (4,5,1,2,3)$.

Source selection: When choosing a food source, the probability of being selected depends on the fitness. However, in the early stage of algorithm search, if the fitness value of a region is particularly good, then the overall trend will be close to the honey source. The competitive honey source will lead to premature convergence. When the fitness value difference between individuals is not large in the late stage of search, it is easy to let the excellent honey source be ignored, so the original artificial bee colony algorithm has a large convergence speed Therefore, we propose an adjustable selection operator calculation method based on differential evolution algorithm. As shown in formula (3).

$$P_i = Q + fit_i / \max(fit_i) (1 - Q)$$  \hspace{1cm} (3)

Here, $fit_i$ is the fitness value of the i-th honey source, $\max(fit_i)$ represents the largest fitness value in the population $fit_i / \max (fit_i) \in (0,1)$. $Q$ is the influence factor of the fitness value and the maximum fitness value of the i-th honey source on the selection probability of honey source. When $Q$ is about 0.9, the effect of fitness value on the selection of honey source is very small. The algorithm can change into random search state as soon as possible. Therefore, the greater $Q$, the more species diversity. In this paper, $Q$ is equal to 0.9 which the algorithm can avoid premature convergence and falling into the local optimal solution.
Reconnaissance bee strategy: When the number of development times of a honey source is greater than the control baseline limit and the fitness is not significantly improved, the honey source is discarded. The algorithm randomly generates a new honey source and sends reconnaissance bees to search. Therefore, the reconnaissance bee can jump out of the local optimal solution in the later stage of the algorithm. The new food sources were generated by RK discrete method.

2.2. Spectrum scheduling

Bianchessi [8] used tabu search algorithm to schedule multiple satellites. Cui Jintian [9] proposed a multi-satellite dynamic mission scheduling model based on mission priority. Zangar N [10] proposed a metric calculation method based on hybrid satellite LTE downlink scheduler. Aiming at the problem of spectrum resource allocation and spectrum scheduling in CR network, Jian Tang [11] proposed a novel multi-channel competition graph to analyze the influence of multi-user interference. In this paper, a spectrum scheduling model is proposed for the downlink band of satellite network. Combined with chaotic distribution, the initial position is generated randomly. The improved discrete artificial bee colony algorithm is used to calculate the priority according to the position and interference matrix, so as to complete spectrum scheduling according to the priority.

Single-channel transmission model: Single-channel consists of a satellite in the centre, m ground stations and N receiving ships. Each receiving equipment is randomly distributed. All receiving devices share one channel. Probability of each channel occupied is exactly the same. \( \mathcal{CU} = \{CU_1, CU_2, \ldots, CU_m \ldots, CU_M\} \) and \( \mathcal{D} = \{D_1, D_2, \ldots, D_m \ldots, D_N\} \). They represent the set of ground stations and the set of receiving ships. Among them, \( CU_m \) and \( D_n \) denotes the ground station \( m \) and the receiving ship \( n \), respectively. On the one hand, the service characteristics of the ground station or receiving ship will affect the probability of receiving signals; on the other hand, the process of satellite downlink band transmitting signals to the ground will be affected by various interference factors due to the long journey and other reasons.

In the process of transmitting data to the ground station or receiving ship in the satellite downlink band, it can be regarded as an optimization problem of directed graph. Therefore, for the channel environment with \( m \) ground station, \( N \) receiving ship and single-channel, the spectrum scheduling model graph can be defined as follows:

- The position matrix of ground station or receiving ship is shown in formula (4). \[ P = \{p_i\}_{N+M} \] \( p_i \) is the location of the \( i \)-th ground station or receiving ship. In this model, chaotic distribution is used to generate a more comprehensive position.

- The interference matrix of satellite signal to ground is shown in formula (5). \[ E = \{e_i|e_i \in (0, e_{imax}}\}_{N+M} \]

- The interference matrix between ground station and receiving ship is shown in formula (6). \[ EP = \{ep_i|ep_i \in (0, e_{pmax}}\}_{N+M} \]

- The network throughput is shown in formula (7). \[ QPS = \sum Q_i/[(M + N) \times T] \]

- The network fairness index is shown in formula (8). \[ F(x) = (x_i)^2/(M + N)(\sum x_i^2) \]
fairer it is. When \( F(x) \) is equal to 1, it means optimal fairness. Resources are allocated to all the devices that can receive data fairly.

Multi-channel transmission model: Different from single-channel, multi-channel has \( K \) channels working at the same time. Every time a satellite sends information to the ground, it needs to consider the transmission scheme of \( k \) channels transmitting \( M + N \) receiving devices, and the use of channels occupied by received signals by ground station and receiving ship is completely random. Based on this model, this paper uses artificial bee colony algorithm to quickly iterate to find the optimal solution and calculate the priority of spectrum resource scheduling, so as to ensure the high-speed and effective transmission of signals.

Considering the above definition, spectrum scheduling is carried out according to the priority order. To minimize the interference target, the mathematical expression of spectrum scheduling problem is established. As shown in formula (9).

\[
\begin{align*}
\min (\alpha P + \beta E + \gamma EP) \\
\text{s.t.} \left\{ \begin{array}{l}
0 \leq F(x) < 1 \\
\max(i) = M + N
\end{array} \right. 
\end{align*}
\]

This is a typical NP hard problem. The resource scheduling problem in this paper can be described as: In single-channel and multi-channel, the optimal priority is calculated according to the data that the channel needs to transmit. The algorithm automatically generates the position of receiving equipment, interference matrix of satellite signal transmission and interference matrix between receiving equipment. The method calculates the optimal priority level, so that the signal transmitted from satellite to ground can be received optimally. The conventional algorithm is not easy to find the optimal solution, and the artificial bee colony algorithm can use the advantages of bee colony search to find the optimal solution of the problem as quickly as possible. Therefore, this chapter uses the adaptive chaotic distribution of differential artificial bee colony algorithm to search the optimal solution of formula (9) to find the optimal priority scheduling order. Among them, \( \alpha \), \( \beta \) and \( \gamma \) control the influence of each variable on the result, where \( \alpha + \beta + \gamma = 1 \). The larger the value is, the deeper the influence of the set value on the optimal solution is. In this paper, according to the actual problem, it is set as 0.2, 0.4 and 0.4.

3. Results & Discussion
The simulation considers that the satellite network continuously sends signals to the ground through the downlink frequency band. In a 100km * 100km area on the ground, there are 25 ground stations and 5 receiving ships to receive signals, realizing the process of single-channel and multi-channel resource scheduling. The chaotic distribution is used to generate the position matrix of the receiver.

![Fig.1 Final resource scheduling sequence result chart of channel ground receiving](image-url)
As shown in Fig. 1, in a single channel, when the satellite sends information to the ground, the first channel to be cut in is the receiving device represented by the largest real point. When the satellite sends data for the second time, the ground equipment represented by the next point receives the data, and so on, until the whole connection is completed, indicating that both the ground station and the receiving ship are involved in the work. In multi-channel, it is assumed that there are six channels working at the same time. As shown above, each channel is connected to a ground station or receiving ship that cuts into a new channel to receive data. The connection is in the order of execution.

![Equity index chart](image1)

**Fig.2 Fairness index curve and throughput curve of scheduling model**

In the process of satellite transmitting signals to the ground, 30 receiving devices (including receiving ship and ground station) are also used for receiving. It can be seen from Fig. 2 that the fairness index gradually decreases with the increase of receiving devices. The overall fairness of multi-channel transmission is closer to 1, and the fairness index is between 0.98 and 1, while the fairness index of single-channel transmission is lower. The flatness index is only between 0.8 and 1, so the multi-channel transmission performance is better by comparison. Besides, throughput of the multi-channel transmission model is much higher than that of the single-channel transmission model. The main reason is that in the multi-channel transmission model, multiple channels are used for parallel transmission, and more information is transmitted per unit time, so as to achieve the minimum interference value, and the overall efficiency is high. Therefore, it can get a larger throughput on the channel with less interference.

![Channel throughput distribution](image2)

**Fig.3 Distribution of multi-channel throughput with the number of receiving devices**

In Fig. 3 when the satellite sends data to the ground, the number of receiving devices ranges from 1 to 50, and other parameters remain unchanged. The experimental results show that the system...
throughput increases with the increase of the number of receiving devices on the ground. The more the number of receiving devices in the system, the more receiving devices can choose to use the channel in the next time slot. The algorithm will select the equipment with less interference to receive the signal which is beneficial to improve the system throughput.

4. Conclusion
In this paper, a spectrum resource scheduling model is established for the satellite terrestrial communication scenario, and a differential artificial bee colony scheduling algorithm based on adaptive chaotic distribution is proposed to calculate the scheduling priority considering the actual environment. Experimental results show that the improved algorithm is more suitable for the requirements of the current simulation environment and improves the fairness index and throughput. Based on the differential artificial bee colony, the satellite to ground communication scheduling system has certain usability.

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