Chaos, Solitons and Fractals 83 (2016) 125–132

Contents lists available at ScienceDirect

Chaos, Solitons and Fractals

Nonlinear Science, and Nonequilibrium and Complex Phenomena

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

Scheduling for single agile satellite, redundant targets problem using complex networks theory

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ARTICLE INFO

Article history:
Received 26 October 2015
Accepted 5 December 2015
Available online 23 December 2015

Keywords:
Agile Earth observation satellites
Scheduling algorithm
Complex networks
Node centrality ranking

ABSTRACT

Scheduling for the Earth observation satellites (EOSs) imaging mission is a complicated combinatorial optimization problem, especially for the agile EOSs (AEOSs). The increasing observation requirements and orbiting satellites have exacerbated the scheduling complexity in recent years. In this paper, the single agile satellite, redundant observation targets scheduling problem is studied. We introduce the theory of complex networks and find similarities between AEOS redundant targets scheduling problem and the node centrality ranking problem. Then we model this problem as a complex network, regarding each node as a possible observation opportunity, and define two factors, node importance factor and target importance factor, to describe the node/target importance. Based on the two factors, we propose a fast approximate scheduling algorithm (FASA) to obtain the effective scheduling results. Simulation results indicate the FASA is quite efficient and with broad suitability. Our work is helpful in the EOSs and AEOSs scheduling problems by using complex network knowledge.

1. Introduction

The scheduling of EOSs is to obtain a feasible observation scheme meeting user requirements [1]. Some researchers characterized the EOSs scheduling problem and developed their mathematical models. Gabrel et al. [2] used graph theory concepts to describe the EOS scheduling problems, Wei-Cheng Lin et al. [3] established an integer programming model and considered a series of constraints, Vasquez et al. [4] developed a logic-constrained knapsack formulation. Based on various models, two types of algorithms were utilized to realize the observation mission. The former methods [2,3,5–7] tried to satisfy the user requirements as much as possible, and the latter algorithms [4,8–11] balanced the computation efficiency to obtain acceptable solutions. Although the EOSs scheduling problems have been comprehensively studied, previous studies could not be directly applied in the AEOSs problems.

The satellite operates fast during the observation imaging process, and its attitude control capability is also limited due to space technology. For instance, most EOSs only have attitude adjustment ability in the direction of the roll axis. As shown in Fig. 1, fixed possible observation time windows reduce the scheduling difficulties, and some scholars defined this kind of Earth observation mission type as a selecting problem [12]. With the development of space technology, the agile satellite with stronger attitude maneuver capability has been widely utilized for the Earth observation. AEOSs could adjust observation attitude along the roll axis, pitch axis and yaw axis. Roll axis and pitch axis rotation change observation start time and corresponding observation position, while yaw axis movement influences the imaging shapes. Fig. 2 [13] shows different observation situations of agile and non-agile EOSs. AEOS improves observation efficiency, but also increases the difficulties of observation scheduling task.

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http://dx.doi.org/10.1016/j.chaos.2015.12.003

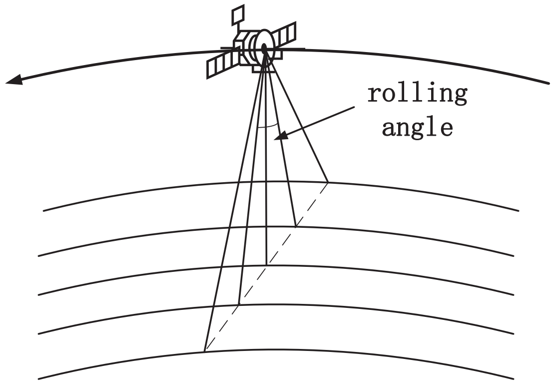

Fig. 1. Satellite attitude control capability of the roll axis. The satellite attitude control capability limits its imaging ability, and only when the satellite orbits in the specific position, the ground target could be observed. During the whole scheduling period, we only have time determined imaging opportunities for part of the ground targets.

Lemaitre et al. [12] provided a comprehensive description of AEOS scheduling problem and analyzed four different methods, Habet et al. [14] proposed a tabu search algorithm to solve the AEOS scheduling problem, and Beaumet et al. [15] considered the feasibility of autonomous decision making on board. Other impressive works related to the AEOS [16–18] have been well studied. These researches both assumed that most candidate targets could be observed in the scheduling mission. However, with the observation requirements constantly growing, real satellites could only observe small part of mission targets. Candidate mission targets appear to be redundant and AEOSs scheduling problems become more complicated.

The theory of complex networks emerged in recent years, and has proved to be a valid tool describing, modeling and quantifying real complex systems in many areas, such as power distribution systems [19], Internet [20], financial markets [21], optimization system [22–24], epidemic dynamics [25–28] and social systems [29–31]. With the help of complex network theory, many problems could be viewed in different angles and tackled in some new ways [32–42]. We find similarities between AEOS redundant targets scheduling problem and the node centrality ranking problem in the complex networks. Inspired by the previous works and research situations, we mainly focus on the redundant observation targets scheduling problem and introduce the concept of complex network in our work.

The paper is organized as follows. In Section 2, we model the scheduling problem as a complex network, regarding each possible observation opportunity as a node and each subsequent node weight as an edge. In Section 3, the node importance factor and target importance factor are defined to rank the graph nodes. Based on the two factors, we propose a fast approximate scheduling algorithm in the AEOS imaging mission. In Section 4, several simulation results and discussions are given to demonstrate the novel method for the scheduling problem. Section 5 summarizes the work.

2. Model: network establishment

To begin with, we propose the following assumptions to clearly describe the single agile satellite, redundant candidate observation targets scheduling problem.

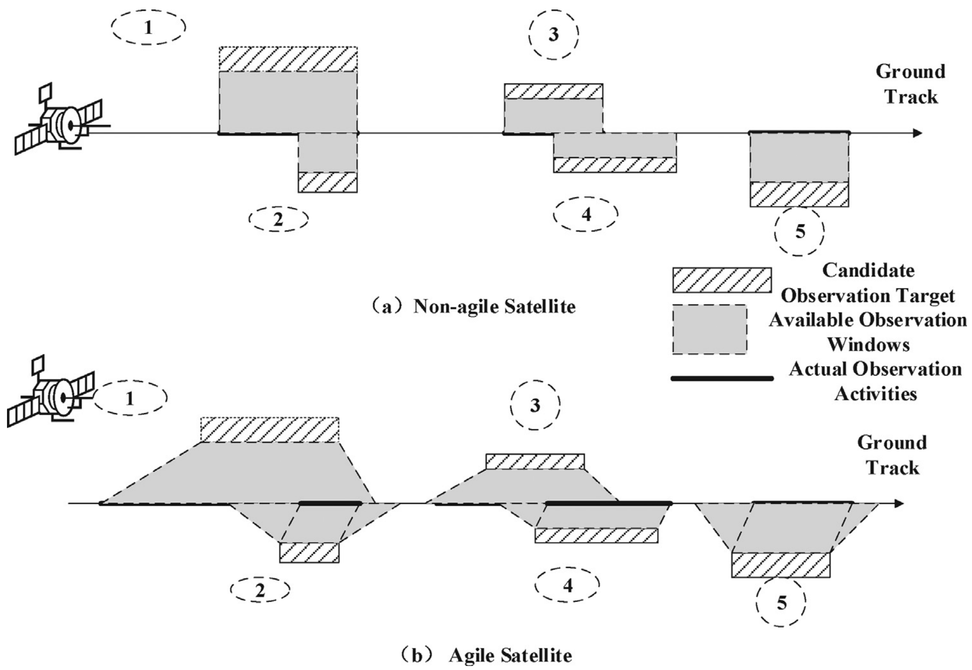

Fig. 2. Different observation situations of agile and non-agile EOSs. The agile satellite greatly increases the length of the satellite observation time windows to the ground targets. It means that the satellite observation start time is no longer unique, as long as the observation mission can be completed within the time window.