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Ant colony optimization based load balancing routing and wavelength assignment for optical satellite networks

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Abstract

An ant colony optimization (ACO) based load balancing routing and wavelength assignment (RWA) algorithm (ALRWA) was put forward for the sake of achieving a fairy load balancing over the entire optical satellite networks. A multi-objective optimization model is established considering the characteristic of global traffic distribution. This not only employs the traffic intensity to modify the light path cost, but also monitors the wavelength utilization of optical inter-satellite links (ISLs). Then an ACO algorithm is utilized to solve this model, leading to finding an optimal light path for every connection request. The optimal light path has the minimum light path cost under satisfying the constraints of wavelength utilization, transmission delay and wavelength-continuity. Simulation results show that ALRWA performs well in blocking probability and realizes efficient load balancing. Meanwhile, the average transmission delay can meet the basic requirement of real-time business transmission.

Keywords load balancing, ACO, RWA, optical satellite network

1 Introduction

Optical satellite networks, which make use of optical ISLs as data carrier between satellites in the constellation, offer many potential advantages compared to radio frequency satellite networks, including a very wide bandwidth, unlicensed spectrum, security, and resistance to jamming [1]. At present, a number of point to point mode of on-board laser communication demonstration tests, such as European data relay system (EDRS) [2], have been successfully carried out. At the same time, the key technologies required to support inter-satellite laser communication have already made significant progress. Coherent communication system greatly improves the receiver sensitivity and brings the potential advantages of multiplexing in frequency domain [3]. Optimizing acquisition tracking and pointing (ATP) technology can effectively increase the scanning range, improve the tracking accuracy, and reduce the system quality, volume and power consumption [4]. Especially, the laser terminal is developing towards miniaturization and lightweight. And vialight's micro laser terminals for applications in the low earth orbit (MLT-LEO), whose weight is less than 15 kg, allow free space optical communication for ultra high data rate ISLs (http://www.vialight.de/space-terminals/). Hence, there is no doubt that optical satellite network will be an important component for the next-generation wide-area space backbone network [5–6]. Furthermore, optical satellite networks based on wavelength division multiplexing (WDM) ISLs have been put forward in Refs. [7–8], which can not only simplify routing decisions but also minimize processing delays [9]. Meanwhile, WDM ISLs technologies, onboard WDM devices and some other related issues have also already been developed [10].

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The RWA problem, especially under the wavelength-continuity constraint, is the most challenging issue in the wavelength-routed optical satellite WDM networks [11]. However, it is proved to be nondeterministic-polynomial-hard (NP-hard) [12]. The fixed-alternate algorithm [9], the integer linear programming (ILP) methods [13–14], and the ACO algorithm [12,15] have been carried out to solve the problem in optical satellite networks. Although these methods can provide better solutions from different aspects, there are still problems with uneven distribution of traffic load over the entire networks.

The density of satellite user distribution varies widely over the globe due to the difference of terrain, climate and economic prosperity. Indeed, satellites serving urban areas dense with users will be busier than satellites covering rural areas [16], and satellites that cover the northern hemisphere with a lot of hot spots are more likely to be congested than those in the southern hemisphere [17]. This user density variations as well as the highly dynamic motion of satellites produce a result that some optical ISLs are congested while others are unused. If there is no effective RWA strategy to cope with the unbalanced distribution of traffic load over the whole network, this will result in a high blocking probability and an inefficient resource utilization. In this paper, we introduces ALRWA algorithm so as to realize a better load balancing over the entire optical satellite networks. In consideration of the global traffic distribution characteristic, a multi-objective optimization model is designed to find a light path with the minimum light path cost under the constraints of wavelength utilization, transmission delay and wavelength-continuity. Moreover, ACO is applied to seek an optimal light path for every connection request.

The remainder of this paper is organized as follows. Sect. 2 presents the system model, while Sect. 3 goes into particulars about the mechanism of ALRWA. Sect. 4 is devoted to the analysis of ALRWA through simulations. Finally, Sect. 5 summarizes the main conclusions of this paper.

2 System model

2.1 Optical satellite network

Fig. 1 highlights the optical satellite network. The optical satellite network is formed by a constellation with optical ISLs, as well as can provide worldwide communication services. The constellation consists of N satellite nodes placed in a grid configuration with P orbital planes and S satellites per orbit. Satellite users connect to the satellites via ground-satellite links (GSLs), and thus are able to communicate with each other.

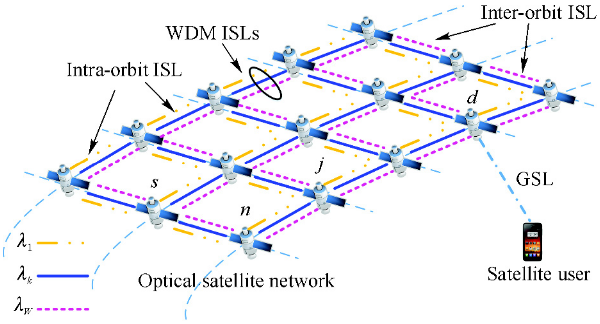

Fig. 1 Optical satellite network

The geographic topology of the optical satellite network changes in a periodic. Therefore, deterministic fashion resulting in a network physical topology that appears to be maintained fixed. The possible physical topologies of constellation networks are variations of the regular bi-directional Manhattan street network (MSN) [5]. Two main configurations are distinguished: polar or near-polar star pattern constellations (π constellations) and inclined delta pattern constellations (2π constellations). As shown in Fig. 2, in a π constellation, in addition to the satellites in the left-most and the right-most orbits, the remaining satellites have four ISLs, that is, a network seam appears between counter-rotating orbits.

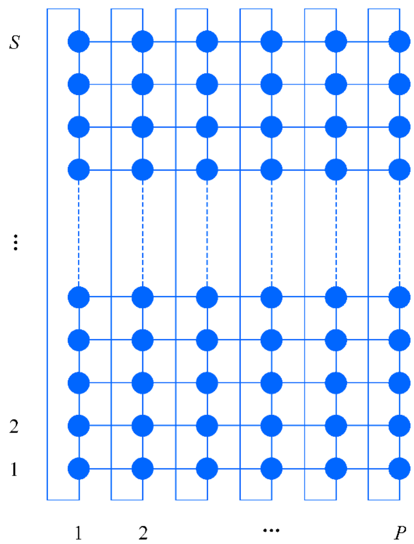

Fig. 2 A network physical topology of π constellation

As is depicted in Fig. 3, each satellite in a 2π constellation has four ISLs, that is, there is no seam