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New optimization model for routing and spectrum assignment with nodes insecurity

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ABSTRACT

By adopting the orthogonal frequency division multiplexing technology, elastic optical networks can provide the flexible and variable bandwidth allocation to each connection request and get higher spectrum utilization. The routing and spectrum assignment problem in elastic optical network is a well-known NP-hard problem. In addition, information security has received worldwide attention. We combine these two problems to investigate the routing and spectrum assignment problem with the guaranteed security in elastic optical network, and establish a new optimization model to minimize the maximum index of the used frequency slots, which is used to determine an optimal routing and spectrum assignment schemes. To solve the model effectively, a hybrid genetic algorithm framework integrating a heuristic algorithm into a genetic algorithm is proposed. The heuristic algorithm is first used to sort the connection requests and then the genetic algorithm is designed to look for an optimal routing and spectrum assignment scheme. In the genetic algorithm, tailor-made crossover, mutation and local search operators are designed. Moreover, simulation experiments are conducted with three heuristic strategies, and the experimental results indicate that the effectiveness of the proposed model and algorithm framework.

1. Introduction

Traditional wavelength division multiplexing networks can only provide the coarse granularity of a single wavelength and cannot suit for different bandwidth connection requirements adaptively, especially in the case of the requested bandwidth being only fractional bandwidth of a wavelength. The continuous growth of various applications, such as internet protocol television, video on demand, cloud computing, requires an efficient networking infrastructure [1]. The recent elastic optical networks can provide the flexible and variable bandwidth allocation to each connection request and get higher spectrum utilization by using the technology of orthogonal frequency division multiplexing [2]. Orthogonal frequency division multiplexing is a multi-carrier modulation technology. It can distribute the high-speed data stream into several orthogonal low-speed subcarriers [3]. The adjacent subcarriers have the spectrum overlapping of a subcarrier bandwidth. This subcarrier is referred to the frequency slot(FS). The elastic optical network can allocate several consecutive frequency slots to each connection request according to the required bandwidth by using orthogonal frequency division multiplexing as a spectrum-efficient modulation technology. Adjacent spectrum bandwidths assigned to two connection requests in the same link should be separated by the guaranteed frequency slots (GFs). Similar to the routing and wavelength assignment (RWA) problem in wavelength division multiplexing networks [4], routing and spectrum assignment(RSA) problem exists in elastic optical network [5]. In order to establish a light-path for the connection request in elastic optical network, three constraints should be satisfied as follows: (1) Spectrum consistency means that the start frequency slot index on different links of a path must be identical; (2) Spectrum continuity means that we must assign consecutive frequency slots to a specific connection request. That is to say, a large connection request can not be divided into several smaller connection requests; (3) A frequency slot on a link should be assigned to one connection request at the most. Generally speaking, the objective of static routing and spectrum assignment is to minimize the maximum index of the used frequency slots with unlimited resource, and to minimize the ratio of blocking with limited resource. Certainly, there are some other optimization objectives, such as energy consumption, cost, etc.

In recent years, more and more researches focus on routing and spectrum assignment problem. Christod, et al. [3] formulated routing and spectrum assignment problem as an integer linear programming (ILP) problem. In addition, they presented a decomposition method

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that divides routing and spectrum assignment into two subproblems: routing problem and spectrum assignment problem. To solve the routing, modulation level and spectrum assignment problem, a novel genetic algorithm with two-population is proposed [6]. Jinno et al. [5] investigated spectral resource allocation problem with the distance adaptive and proposed a heuristic algorithm based on the fixed-alternate routing strategy [7] and first-fit strategy [8]. A technique for the performance analysis of the routing and wavelength assignment algorithm, which uses the first-fit [8], is proposed [9]. The concept of channels for the representation of contiguous spectral resources is introduced [10], and a strategy of pre-computing, which can reduce the problem complexity considerably, is proposed. Zhu et al. [11] investigated dynamic routing and spectrum assignment problem and proposed two types of hybrid single-/multi-path routing schemes. Zhang et al. [12] proposed a multi-layer auxiliary graph to solve the routing problem in electrical layer and spectrum assignment problem in optical layer. Rosa et al. [13] introduced new definitions of the blocking events and developed a framework based on Markov Model to calculate probabilities under dynamic connection request conditions. To solve routing and spectrum assignment problem of the inter-rack connection requests, an integer linear programming formulation and a heuristic algorithm are presented [14]. In the elastic optical networks of supporting cloud computing applications, Fallahpour et al. [15] presented an energy-efficient many-cast routing and spectrum assignment (EEM-RSA) algorithm. However, those researches did not take the insecure nodes into account.

In this paper, we investigate a static (off-line) routing and spectrum assignment problem, where traffic demands are known in advance. Different from the previous works, insecure nodes for connection requests are taken into account. As a result of the existence of network attack, information security has attracted more and more attention. Generally speaking, each connection request has an insecure node set. In order to ensure the security of a connection request, secure path, which does not include any insecure nodes, should not be selected. Since spectral resource is an important resource in elastic optical network, we establish a new optimization model with the guaranteed security by minimizing the maximum index of the used frequency slots, which is used to determine an optimal scheme of routing and spectrum assignment. To solve the optimization model effectively, tailor-made crossover, mutation and local search operators are designed. Based on these, an efficient hybrid genetic algorithm is proposed. The major contributions of this study are summarized as follows:

- To guarantee the information security and decrease the possibility of network attack on some nodes, insecure nodes, which are insecure for connection requests, are taken into account.
- We establish a new optimization model with the guaranteed security by minimizing the maximum index of the used frequency slots, which is used to determine the optimal scheme of routing and spectrum assignment
- To solve the optimization model effectively, tailor-made crossover, mutation and local search operators are designed. Based on these, an efficient hybrid genetic algorithm is proposed.

The rest of this paper is organized as follows. Section 2 gives the problem formulation and establishes a new global optimization model. To solve the optimization model effectively, we propose a hybrid genetic algorithm in Section 3. In Section 4, simulation experiments are conducted, and experimental results are presented and analyzed. This paper is concluded with a summary in Section 5.

2. A new global optimization model

2.1. Problem formulation

Let's use a directed graph $G = (V, E)$ to denote a network, where $V = \{v_1, v_2, \ldots, v_N\}$ is the set of the network nodes with N being the number of nodes and v_i the i-th optical node, and $E = \{l_{ij} | v_i, v_j \in V\}$ represents optical fiber link set with N_E being the number of links in a network and l_{ij} the link between node v_i and node v_j in the network topology. Let $F = \{f_1, f_2, \ldots, f_{N_F}\}$ be a set of available frequency slots in each link, and N_F be the number of frequency slots. $R = \{r_1, r_2, \ldots, r_{N_R}\}$ represents a connection request set, where N_R is the number of connection requests. A connection request $r_k (r_k \in R)$ can be described as $r_k = (s_k, d_k, T_k, \Omega_k)$, where s_k,d_k and T_k denote the source node, destination node and required capacity, respectively. Ω_k is a node set, which includes all the insecure nodes for connection request r_k. In our work, We assume that the connection requests with the same source node and destination node, have the same insecure node set. $Q_k = \{Q_k^1, Q_k^2, \ldots, Q_k^K\}$ denotes a candidate path set of the connection request $r_k (r_k \in R)$, where K is the number of paths determined previously. In our work, we assume that each frequency slot has the same bandwidth C_{fs}, and the capacity of an frequency slot is $ML \times C_{fs}$, where ML is the bits per symbol in a specific modulation level. ML can be selected as 1, 2, 3 and 4 for different modulation levels of BPSK, QPSK, 8QAM and 16QAM. If ML_k denotes the modulation level of connection request r_k selected, it can be calculated by

$$ML_k = \max\left\{ ML | L(ML) \geq \sum_{l_{ij} \in Q_k^q} w_{ij} \right\} \tag{1}$$

where $L(ML)$ is the transmission distance of modulation level ML, and w_{ij} is the distance of link l_{ij}. The number of frequency slots B_k of r_k required can be calculated by

$$B_k = \left\lceil \frac{T_k}{ML_k \times C_{fs}} \right\rceil \tag{2}$$

2.2. Proposed model

Before setting up a global optimization programming model, we first introduce some notations that will be used throughout the paper as follows:

- $F_{l_{ij}}$: the maximum index of the used frequency slots on link l_{ij}.
- Q_k: the candidate secure path set of the connection request $r_k (r_k \in R)$, and $Q_k = \{Q_k^1, Q_k^2, \ldots, Q_k^K\}$.
- ${Q_k}^q$: the q-th path in Q_k.
- λ_k^q: a boolean variable, $\lambda_k^q = 1$ if and only if path ${Q_k}^q$ is occupied by connection request r_k, otherwise, $\lambda_k^q = 0$.
- $V(Q_k^q)$: a node set that includes all the nodes in path ${Q_k}^q$.
- $f_{k,l_{ij}}$: the start frequency slot index of connection request r_k on link l_{ij}.
- $\phi_{k,l_{ij}}^{q,u}$: a boolean variable, $\phi_{k,l_{ij}}^{q,u} = 1$ if and only if the u-th frequency slot on link l_{ij} of the path ${Q_k}^q$ is occupied by connection request r_k, otherwise, $\phi_{k,l_{ij}}^{q,u} = 0$.
- $r_k \prec r_{k'}$: connection requests r_k and $r_{k'}$ occupy the same link l_{ij}, and the start frequency slot index of r_k is smaller than that of $r_{k'}$ on link l_{ij}.
- GF: the number of guardian frequency slots.

Our objective is to minimize the maximum index of the used frequency slots to serve all the connection requests. To achieve this purpose, an optimal routing and optimal spectrum assignment scheme should be determined. Since the maximum index of the used frequency slots is calculated by

$$F = \max_{l_{ij} \in E} \left\{ F_{l_{ij}} \right\}. \tag{3}$$

The objective function can be expressed by