Expert Systems with Applications 42 (2015) 7781–7796

Contents lists available at ScienceDirect

Expert Systems with Applications

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

Towards solving practical problems of large solution space using a novel pattern searching hybrid evolutionary algorithm – An elastic optical network optimization case study

Michał Przewoźniczek [a,*], Róża Goścień [b], Krzysztof Walkowiak [b], Mirosław Klinkowski [c]

[a] Department of Computational Intelligence, Wroclaw University of Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland
[b] Department of Systems and Computer Networks, Wroclaw University of Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland
[c] National Institute of Telecommunications, 1 Szachowa Street, 04-894 Warsaw, Poland

ARTICLE INFO

Article history:
Available online 11 June 2015

Keywords:
Genetic algorithm
Large solution space size
MuPPetS
Gene patterns
Linkage learning
Optimization
Elastic optical networks
Routing and spectrum allocation
Anycasting

ABSTRACT

The fast social and economic development observed in the recent years brings up new challenging optimization problems. These problems are often very hard not only because of their computational complexity, but also due to their enormous solution space size. Therefore, this paper proposes an effective optimization method, based on the novel Multi Population Pattern Searching (MuPPetS) Algorithm, to solve optimization problems characterized with very large solution space. As a case study problem, we focus on the problem of routing and spectrum allocation with joint anycast and unicast traffic demands that arises in the field of optical networks optimization. The proposed method is adjusted to the problem with proper solution encoding, hybridization using a local search algorithm, and dedicated mechanisms necessary to improve method convergence. The above adjustments are required to make the method effective against test cases with solution space size of up to 10^{3700} points (sets of values of the choice variables). The paper compares the performance of the proposed method with other reference methods known from the literature. Another key contribution of this paper is presentation of the complicated dependency between fitness function evaluation number (FFE) and real computation load, which are used to evaluate effectiveness of the proposed technique. The analysis is supported with proper empirical tests and their analysis.

1. Introduction

In recent years, we have been observing fast development of many innovative systems applied in a wide range of human activities including fields like engineering, marketing, information management, crisis management, stock trading, strategic management, network management, telecommunications, medicine, chemistry, business, and production management. Many of these new systems are characterized with a high complexity and huge size, what makes the optimization of their performance very challenging. Most of the optimization methods proposed in the past and based on classical expert and intelligent techniques cannot ensure the expected efficiency of such systems mostly due to the enormous solution space of the analyzed optimization problems. Therefore, there is a need to work on new intelligent optimization methods that can cope with these arising challenges.

The main goal of this paper is to propose an effective optimization method based on the evolutionary algorithm approach to solve an optimization problem characterized with a very large solution space that has arisen recently in the context of optical networks. In more detail, we consider a routing and spectrum allocation (RSA) problem with anycast and unicast flows in Elastic Optical Networks (EONs). The introduction of the EON concept (Jinno et al., 2009) follows mostly from exponentially growing network traffic and advent of many network services like, cloud computing, Content Delivery Networks (CDNs), IP TV, video streaming, Internet of Things (Christodoulopoulos, Tomkos, & Varvarigos, 2011; Latre, Famaey, De Turck, & Demeester, 2014; Walkowiak & Klinkowski, 2013). In EONs, the frequency spectrum that is available for transmitting optical signals in an optical fiber link is divided into narrow frequency segments that are called *slices*. According to ITU-T, the width of a slice is equal to 6.25 GHz (ITU-I Recommendation, 2012). By grouping an even number of

* Corresponding author.
E-mail addresses: michal.przewozniczek@pwr.edu.pl (M. Przewoźniczek), roza.goscien@pwr.edu.pl (R. Goścień), krzysztof.walkowiak@pwr.edu.pl (K. Walkowiak), M.Klinkowski@itl.waw.pl (M. Klinkowski).

http://dx.doi.org/10.1016/j.eswa.2015.05.040
0957-4174/

frequency slices we can create a *channel* that is used to transmit data. The RSA problem consists in finding, for each demand from a set of traffic demands, a routing path (a sequence of network links that connect source and destination of the demand) and unoccupied spectrum resources on this path (a channel) that support volume of the demand (in Gb/s). The RSA problem is an NP-complete problem and can be solved in optimal way (for example with Integer Linear Programming (ILP) models) only for relatively small problem instances. In this work, we assume that two types of network flows are transmitted in the network, namely, classical unicast (one-to-one) flows and, related to new network services, anycast (one-to-one-of many) flows. The key motivation behind anycasting is a growing popularity of network services provided by large data centers (DCs) spread geographically in the networks, e.g., cloud computing, Content Delivery Networks (CDNs) distributed storage (Latre et al., 2014).

Hence, in this paper, we focus on the RSA problem with joint optimization of unicast and anycast traffic in EONs. This practical problem is difficult not only because it is NP-complete, but because it is also characterized by an extremely large solution space. Here, the main part of experiments is executed for test cases of solution space starting from 10^{750} up to 10^{3700} solution points (see Section 6.1). Please notice that considering so large solution spaces is rarely equaled even in papers considering very hard practical problems. The above characteristics lead to a conclusion that to find effective tools for solving such problems evolutionary algorithms (EA) should be considered. Therefore, in this paper we propose a novel evolutionary algorithm for joint optimization of unicast and anycast traffic in EONs, more effective than already proposed methods (Aibin & Walkowiak, 2014; Goścień, Walkowiak, & Klinkowski, 2015; Walkowiak, Klinkowski, Rabiega, & Goscien, 2014). To outperform Tabu Search and Simulated Annealing methods designed for the RSA problems, the Multi Population Pattern Searching Algorithm (MuPPetS) was chosen as the research start point. The MuPPetS is a kind of the genetic algorithm (GA) based method used for solving discrete optimization problems. It combines coevolution and linkage learning techniques and was found very effective when used in solving theoretical (Kwasnicka & Przewozniczek, 2011) and practical problems (Walkowiak, Przewozniczek, & Pajak, 2013). To reach the main objective of this paper, a new algorithm called MuPPetS-EON is proposed. The general framework of the MuPPetS-EON method is based on classical MuPPetS, but innovative and efficient modifications are proposed using proper problem dependent encoding and specialized operators. The dedicated problem encoding combines local search, typical discrete problem encoding (gene value is the path chosen for the demand the gene refers to) and ordering. The use of the local optimization improves the method convergence speed to good solutions, while the use of ordering prevents the search space limitation that may be caused by local search and may make good solutions unreachable for the method. The other adjustment of MuPPetS-EON proposed in this paper is a dedicated mutation operator that uses a special measure to rank routing paths. Computation tests performed for MuPPetS-EON using the dedicated mutation operator and without this mechanism show clearly superiority of the new approach. It should be noted that the novel elements of the MuPPetS algorithm proposed for the considered RSA problem may be used in the context of other optimization problems characterized with extremely large solution spaces.

In the genetic algorithms field, it is common to measure the computation load only by fitness function evaluation number (FFE). This practice is not always acceptable and sometimes used incorrectly. Among all, this topic is widely commented and analyzed with proper examples in Kwasnicka and Przewozniczek (2011). The use of FFE as a computation load measure is also not allowed in the case of methods concerned in this paper. Therefore, according to the state-of-art of the current literature, one of the objectives of this paper is to present in details the complicated dependency between FFE number and the real computation load used by a method. This topic is widely discussed in Sections 4.3 and 6.5.

Finally, the third objective of this paper is to present the results of extensive numerical experiments and examine performance of MuPPetS-EON and other methods proposed in the literature. The set of competing methods was extended by reporting results of other reference optimization algorithms embracing optimal branch-and-cut method (only for small networks), Tabu Search, simple genetic algorithm and Random Search.

To summarize, the main contribution of this paper is a detailed description and evaluation of an innovative evolutionary algorithm MuPPetS-EON designed to solve the RSA problem characterized with extremely large search solution space. Extensive numerical experiments run on real test cases clearly shows that MuPPetS-EON provides results very close to optimal ones for small problem instances (optimality gap on average is <0.1% for problems of solution space up to 10^{62}) as well as that MuPPetS-EON outperforms other heuristic for larger problem instances.

The rest of paper is organized as follows. In Section 2, we discuss related works. Section 3 includes an ILP formulation of the addressed optimization problem. In Section 4, we describe our novel evolutionary algorithm. In Section 5, we briefly describe the dedicated Tabu Search method. Section 6 presents results of extensive numerical results. Finally, last section concludes this work.

2. Related works

The majority of papers related to the use of metaheuristic algorithms for optimization problems in EONs make use of evolutionary algorithms and, their subclass, genetic algorithms. These papers address static network planning problems (Capucho & Resendo, 2013; Cerutti, Martinelli, Sambo, Cugini, & Castoldi, 2014; Eira, Santos, Pedro, & Pires, 2014; Klinkowski, 2013; Lezama, Castanon, Sarmiento, & Martins, 2014; Long, Xiang, Wei, & Zuqing, 2012; Long et al., 2013; Patel, Ji, Jue, & Ting, 2012; Velasco, Wright, Lord, & Junyent, 2013; Wei, Xiang, Long, & Zuqing, 2012), and dynamic scenarios (Almeida et al., 2013; Huang & Li, 2014; Long et al., 2012; Xiang, Wei, Long, & Zuqing, 2012) as well. Generally, the optimization criteria in these problems are spectrum usage and request blocking probability for static and dynamic cases, respectively. The above-mentioned papers describe interesting implementations and extensions of the standard genetic or evolutionary mechanism. For instance, the authors of Long et al. (2012) discuss a multi-population based evolutionary approach. The authors of Patel et al. (2012) propose to decompose the Routing, Wavelength Assignment and Spectrum Allocation (RWSA) problem into two subproblems: (i) routing problem and (ii) wavelength assignment and spectrum allocation problem. Next, they combine two metaheuristic methods to solve these subproblems: genetic algorithm for the former one and simulated annealing for the latter one. Concurrently, the authors of Cerutti et al. (2014), Velasco et al. (2013) and Xiang et al. (2012) discuss multi-objective algorithms. In Xiang et al. (2012), the genetic algorithm is proposed that minimizes spectrum usage if requests are not likely to be blocked (small network traffic) and request blocking probability otherwise. The authors of Velasco et al. (2013) propose an evolutionary-based method that faces optimization criteria defined as a combination of spectrum usage and network cost, wherein the authors of Cerutti et al. (2014) present genetic algorithm that balances contrasting objectives of minimizing the