Hyper-heuristic Methods for Physical Impairment Aware Routing and Wavelength Assignment

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1 Introduction

In this paper, the physical impairment aware routing and wavelength assignment (PI-RWA) problem which is a sub-problem of Virtual Topology Design (VTD), is solved using Hyper-heuristic approaches while considering some physical constraints.

Routing and Wavelength Assignment (RWA) problem aims to establish lightpaths (optical connections) by finding a physical route and assigning a wavelength over a physical topology. In the static RWA problem, all connection requests are known in advance. Hence, the order of establishing lightpaths affects the resource usage and changes the solution.

To ensure transmission quality, the BER of each lightpath should be below a given value. The noises considered in this study that affect the lightpaths are the Amplified Spontaneous Emission (ASE) noise and the crosstalk XT noise, which are calculated according to the model in [1]. As the light propagates over fiber links, its power decreases because of the impairment of the fiber itself. Erbium-doped fiber amplifiers (EDFA) are used to amplify the light power, but while doing this, EDFA induces a noise known as ASE. On the other hand, the signal of a lightpath that goes through the optical cross-connects affects the other signals of the lightpaths that have the same wavelength, which is known as cross-talk (XT) noise. Each established lightpath will affect the BER of previously established lightpaths.

2 Solution Approaches

Hyper-heuristics (HHs) are algorithms that coordinate the heuristics used for solving a problem [2]. In this study a Tabu Search Based HH (TSHH) and an Ant Colony Optimization Based HH (ACHH) are used to minimize the total Bit Error Rate (BER) of the established lightpaths. Both ACHH and TSHH use constructive heuristics as low level heuristics.

A solution in both of the proposed approaches is represented as an array of constructive heuristics that shows the order in which they will be applied to route the next lightpath. The Tabu search method starts from an array consisting of SP heuristics for all lightpaths and randomly changes one of the low level heuristics on the array with another randomly selected one to search on the heuristics space at each iteration [3]. Tabu search continues until a constant number of iterations is reached. Max-Min Ant System is used as the ACHH. Ants, which are placed initially on random nodes (low level heuristics), start to move from one node to another according to pheromone values on the edges. Each move of an ant is a step of the solution construction [4]. This continues until a fixed number of iterations is reached. After a solution is generated, its quality is calculated at each iteration of the algorithms. As wavelength assignment, the least used first strategy is used. After routing the lightpath and assigning the wavelength, the BER of the lightpath is calculated using analytical PI models.

Four low level heuristics are used in both HHs. Shortest Path (SP) selects the shortest physical route for the lightpath. K-Shortest Path (KSP) finds the k-shortest paths over the physical topology and selects one of them randomly. Least Congested Path (LCP) finds the k-shortest paths and selects the lowest congested one, where the congestion of a path is the maximum number of unavailable wavelengths for the links of the path. Lowest BER (LBER) finds the k-shortest paths and selects the one which has the lowest BER.

Table 1: Means and Standard Errors of BERs for 3-connected virtual topologies on NSFNET

Wavelengths		SP	KSP	LCP	LBERP	TSHH	ACHH
8	Mean	$2.42 \text{x} 10^{-11}$	$4.87 \text{x} 10^{-8}$	$4.32 \text{x} 10^{-10}$	$5.69 \text{x} 10^{-14}$	$1.15 \text{x} 10^{-10}$	$1.85 \text{x} 10^{-11}$
	StErr	$6.95 \text{x} 10^{-12}$	$6.81 \text{x} 10^{-9}$	$1.05 \text{x} 10^{-10}$	$2.23 \text{x} 10^{-14}$	$2.68 \text{x} 10^{-11}$	$6.69 \text{x} 10^{-12}$
16	Mean	$3.62 \text{x} 10^{-21}$	$1.46 \text{x} 10^{-12}$	$8.06 \text{x} 10^{-20}$	$1.95 \text{x} 10^{-25}$	$3.30 \text{x} 10^{-17}$	$1.67 \text{x} 10^{-17}$
	StErr	$1.92 \text{x} 10^{-21}$	$4.48 \text{x} 10^{-13}$	$1.71 \text{x} 10^{-20}$	$8.95 \text{x} 10^{-26}$	$1.47 \text{x} 10^{-17}$	$8.05 \text{x} 10^{-18}$

3 Results

We performed experiments using common benchmark physical networks: NSFNET (14 nodes, 21 links) and a telco network (21 nodes, 43 links). We assumed 8 and 16 wavelengths per fiber. We randomly generated twenty 3-, 4-, 5-connected virtual topologies and performed 10 runs for each approach per topology. TSHH and ACHH run for a fixed number of iterations. To provide a fair comparison, we allow the same number of source-destination pair permutations to the single heuristics. The threshold BER value for feasible lightpaths is taken as 10^{-9}.

The mean and standard error BER values for the 3-connected virtual topologies for the NSFNET are given in Table 1. Similar results are obtained for the telco network and the other connectivity degrees. For the tests with 16 wavelengths, LBER has the best performance. The average performance of ACHH is comparable with others. Furthermore, for some virtual topologies it gave the best results. On the other hand TSHH also gives feasible solutions but its performance is lower than ACHH. SP gives better solutions because ASE noise becomes lower when the path is shorter. We expected that if the number of wavelength is decreased, the performance of SP will be lowered as it does not consider the XT noise. Indeed, the results for 8 wavelengths show that the performance of SP is no longer better than ACHH. SP cannot produce solutions as good as the 16 wavelengths case when XT noise is increased while ACHH combines different low level heuristics, and thus it can produce better results than SP.

We also compared the running times of the methods. We saw that SP is the fastest method while LBER is the slowest and ACHH is the second fastest. Since we need to solve the PI-RWA as fast as possible, both ACHH and SP are good candidates.

4 Conclusion

We proposed two HHs, ACHH and TSHH, for solving the PI-RWA problem while considering ASE and XT noises. Both methods give feasible solutions. When we decrease the available number of wavelengths, the performance of single heuristics drops, while the performance of ACHH increases. The experiments showed that ACHH is slower than SP but faster than the others. Since the PI-RWA is a sub-problem of VTD it should be solved in a short time. This makes the ACHH the best choice.

References

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