Performance Analysis of NIHs for Survivable Virtual Topology Mapping[1]

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1. Introduction

Optical networking (Mukherjee, 1997) is the most effective technology to meet the high bandwidth network demand. The high capacity of fiber used in optical networks, can be divided into hundreds of different transmission channels, using the WDM technology. Each of these channels work on different wavelengths and can be associated with a different optical connection, called lightpath. All the lightpaths set up on the network form the virtual topology (VT). Given the physical and the virtual topologies, VT mapping problem is to find a proper route for each lightpath.

Any damage to a physical link (fiber) on the network causes all the lightpaths routed through this link to be broken. Survivable VT mapping problem is to design the virtual layer such that the virtual topology remains connected in the event of a single link failure.

Since the VT mapping problem is known to be NP-complete (Modiano & Narula-Tam, 2002), heuristic approaches should be used. In this study, as a solution to the problem, we propose evolutionary algorithms (EA) due to their successful applications on NP-complete problems and ant colony optimization (ACO) due to their successful performance on constrained combinatorial optimization problems. As a result of the experiments, we show that both ACO and EA can solve the problem in less than a minute.

The rest of the paper is organized as follows. In section 2 the problem is defined and related literature is given. Next, the details of how NIHs are applied to our problem are given in section 3. Finally, in section 4, the experimental results are given and discussed thoroughly.

[1]An extended version of this paper can be found in Proceedings of IEEE Globecom'09, Hawaii, USA, Nov.30 - Dec.4, 2009

2. Problem Definition and Related Work

In this work, given the physical and the virtual topologies, our aim is to find a survivable mapping of the VT. There are two main constraints of the problem. The survivability constraint states that all the lightpaths of a cut-set in VT cannot be routed using the same physical link. Capacity constraint ensures that the number of wavelengths on a physical link does not exceed its capacity. Our objective is to minimize the total number of physical links used in the whole physical topology.

The survivable VT mapping problem was solved using tabu search (Crochat & Le Boudec, 1998), (Nucci et al., 2001), local search (Ducatelle & Gambardella, 2005) and SMART (Kurant & Thiran, 2007) algorithms. ILP (Integer Linear Programming) formulation to the problem is given in (Modiano & Narula-Tam, 2002).

3. Application of the NIHs to the Problem

Designing a solution encoding is crucial in EA and ACO performance. For the solution encoding, first, the k-shortest paths for each lightpath are determined. Then, a solution candidate is represented as an integer string of length l, where l is the number of lightpaths in the VT. Each location on the solution string gives the index of the shortest path for the corresponding lightpath, which can take on values between $[1..k]$, where k is the predefined number of shortest paths for the lightpaths.

In EA, constraint violations are considered as penalties in the fitness evaluation stage. In ACO, constraints are taken into consideration during solution construction, therefore constraint violation is not possible.

3.1 Evolutionary Algorithm Design

A steady state EA with duplicate elimination is used. After a random initial population generation, binary tournament selection and uniform crossover are applied as EA operators. If mutation occurs on a gene, its current value is replaced by the index of the least similar shortest path for the corresponding lightpath, similarity being defined as the number of common physical links. The offspring replaces the worst individual in the population.

Violations of the constraints for the problem are included as penalties in the fitness function. The penalty for an unsurvivable solution is determined as the sum of the total number of lightpaths that become disconnected in the event of each physical link failure (Crochat & Le Boudec, 1998). A capacity constraint violation adds a penalty value which is proportional to the total number of physical links which exceed the predetermined wavelength capacity. These two penalties are multiplied with a penalty factor and added to the fitness of the solution.

3.2 Ant Colony Algorithms Design

In this study, we chose elitist ant system (EAS) as the ACO algorithm. The ants are sorted in decreasing order according to the quality of the solutions they constructed.

Solutions are constructed by applying the following simple constructive procedure to each ant: (1) choose a start lightpath and one of its shortest paths, (2) use lightpath pheromone to select the next lightpath (3) use shortest path pheromone together with heuristic values to probabilistically determine the path between the nodes of the corresponding lightpath, until all lightpaths have been visited. If the ant cannot select a shortest path that makes the solution feasible, i.e., all alternative shortest paths violate the survivability and the capacity constraints, this ant is removed from the current iteration.

3.3 An Example

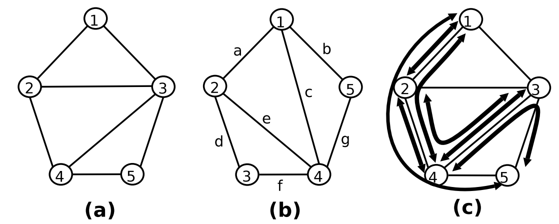

Figure 1. a. Physical Topology, b. Virtual Topology c. Mapping for Example Individual [1 1 2 3 1 1 2]

Consider the physical and virtual topologies given in Figure 1. In Table 1, the second row shows the lightpaths as source-destination node pairs. Three shortest paths for the corresponding lightpath are given in the following rows.

Assume we have a solution encoded as [1 1 2 3 1 1 2]. This encoding means that the lightpaths a and c use the 1^{st} shortest path ((1-2) and (1-2-4), respectively) and lightpath b uses 2^{nd} shortest path (1-2-4-5), etc. If we sum up the number of physical links used in this solution, we have 12 as the resource usage.

For this sample solution, a failure on the physical links connecting nodes 1-2, 2-4, or 3-4, would result in the virtual topology disconnection. If 1-2 link is broken, 3 lightpaths (a,b, and c), if 2-4 link is broken, 4 lightpaths (b,c,d, and e), and if 3-4 link is broken, 2 lightpaths (d and f) would not find an alternative path to communicate. As a result, in EA, a penalty of $9 * p$ is added to the fitness, where p is the penalty factor. On the other hand, since ACO checks the constraints during solution construction, such a solution would not be generated.

Table 1. Three different shortest paths for the lightpaths of the example virtual topology given in Figure 1.

	lightpath						
	1-2 (a)	**1-4 (c)**	**1-5 (b)**	**2-3 (d)**	**2-4 (e)**	**3-4 (f)**	**4-5 (g)**
sp_1	1-2	1-2-4	1-3-5	2-3	2-4	3-4	4-5
sp_2	1-3-2	1-3-4	1-2-4-5	2-1-3	2-3-4	3-2-4	4-3-5
sp_3	1-3-4-2	1-3-2-4	1-2-3-5	2-4-3	2-1-3-4	3-5-4	4-2-3-5

In EA, if a mutation occurs on the second gene of this sample individual, the new individual becomes [1 2 2 3 1 1 2].

4. Experiments

In this section, we present the results obtained from the experiments to evaluate the efficiency of our NIHs. For performance comparisons, we used two metrics, namely success rate, and resource usage. Success rate is the percentage of program runs in which a solution that does not violate the constraints is found. Resource usage is the total number of physical links used throughout the network.

For the experiments, we used two different physical topologies: the 14-node NSF network and a 24-node network (see (Mukherjee, 1997) chapter 11 pp.557). For each physical topology we created 100 random VTs with average connectivity degrees of 3, 4, and 5. We assumed 10 wavelengths per physical link.

4.1 Experimental Results

We performed our initial experiments on the NSF network. Both EA and ACO were able to find feasible solutions of equal quality for all VTs, with 100% success rate. In this paper we report the results for the larger network. For the experimentation, we selected the EA and ACO with the most promising parameter sets according to a set of tests. For each algorithm and VT connectivity degree, we examined three different numbers of alternative shortest paths: 5, 10, and 15.

The results of the experiments are given in Tables 2- 5. Table 2 shows the success rates of both heuristics averaged over 2000 runs (20 runs per VT instance) while Table 3 shows the average of resource usages calculated using only the results of the successful runs. The comparison of our NIHs with basic and relaxed ILP are given in Tables 4 and 5.

A quick observation of Table 2 shows that success rates for both algorithms are very high. Generally ACO achieves higher success rates. From Table 2, we can see that success rates increase with the increase in the number of alternative shortest paths.

Table 2. Success rates

	5 shortest paths		10 shortest paths		15 shortest paths	
	EA	ACO	EA	ACO	EA	ACO
3	97	98	98	100	97	100
4	99	98	100	100	100	100
5	100	100	100	100	99	100

The probability of random candidate solutions being survivable increases with the connectivity degree of the VT. Therefore, for higher connectivity degrees of VTs, both algorithms have higher success rates.

Table 3 shows that the resource usage increases slightly with the increase in the number of alternative shortest paths, especially for EA. This is an expected result, since, the probability of getting stuck at local optima is higher in larger search spaces and both algorithms are allowed to run up to a predefined maximum time. If the run times are increased, the resource usage results for different number of shortest paths will converge.

Table 3. Resource usages

	5 shortest paths		10 shortest paths		15 shortest paths	
	EA	ACO	EA	ACO	EA	ACO
3	111	110	112	110	113	110
4	144	143	145	143	146	144
5	182	181	183	181	186	181

To assess the quality of our solutions, we also implemented basic ILP and ILP Relaxation-1 given in (Modiano & Narula-Tam, 2002), for all connectivity degree VTs. We implemented these ILP formulations using the CPLEX software package. However, since the problem is a large one, we could only solve the problem using basic ILP for only 58% of 3 connected VTs.

Table 4. Number of feasible solutions

	EA	ACO	ILP-Relaxation	Basic ILP
3	100	100	52	58
4	100	100	88	0
5	100	100	100	0

From Table 4, we can see that our NIHs can find a feasible solution for all test sets, although, it is not the case for basic and relaxed ILP. Moreover, if we compare the resource usages of our feasible solutions to the optimum ones found using basic or relaxed ILP as in Table 5, we can see that at least 97% of our solutions are the optimum.

Table 5. Number of solutions having optimum resource usage

	3	4	5
EA	97	97	100
ACO	98	98	100

5. Conclusion

High success rates show that both heuristics are promising for the survivable VT mapping problem. Since the time needed to find a feasible solution is less than a minute, these heuristics can easily be applied to real world applications.

References

Crochat, O., & Le Boudec, J. Y. (1998). Design protection for wdm optical networks. *Journal on Selected Areas in Communications*, 1158–1166.

Ducatelle, F., & Gambardella, L. M. (2005). Survivable routing in ip-over-wdm networks: An efficient and scalable local search algorithm. *Optical Switching and Networking*, *2(2)*, 86–99.

Kurant, M., & Thiran, P. (2007). Survivable routing of mesh topologies in ip-over-wdm networks by recursive graph contraction. *IEEE Journal on Selected Areas in Communications*, *25(5)*, 922–933.

Modiano, E., & Narula-Tam, A. (2002). Survivable lightpath routing: A new approach to the design of wdm-based networks. *IEEE Journal on Selected Areas in Communications*, *20(4)*, 800–809.

Mukherjee, B. (1997). *Optical communication networks*. New York: McGraw-Hill.

Nucci, A., Sanso, B., Crainic, T., Leonardi, E., & Marsan, M. A. (2001). Design of fault-tolerant virtual topologies in wavelength-routed optical ip networks. *Proceedings of IEEE Globecom*.