Wavelength Assignment in WDM Networks – A Comparison of Approaches

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Abstract

Two heuristic search techniques, genetic algorithm and simulated annealing, together with a simple heuristic procedure, based on the graph coloring, are applied in searching for optimal solution of the wavelength assignment problem in all-optical transmission networks with wavelength division multiplex (WDM). The assignment results are compared.

Keywords

Genetic Algorithm, Simulated Annealing, Graph Coloring, Wavelength Division Multiplex, Wavelength Assignment

1 INTRODUCTION

The wavelength assignment as optimization problem appears in all-optical transmission networks with wavelength division multiplex (WDM). An optimization goal could be defined as: how to assign wavelengths, fibers and optical links in order to minimize total fiber length (TFL) in the network, fulfilling traffic and reliability requirements.

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The paper describes an application of genetic algorithm (GA), simulated annealing (SA), and a heuristic procedure based on graph coloring (GC), in order to compare methods according to optimization results.

2 WAVELENGTH ASSIGNMENT IN WDM NETWORKS

In *WDM* a number of channels (N_λ) are transmitted on a single fiber by using different wavelengths, referred to as wavelength channels (*WCH*). A single *WCH* carries the traffic of standard bit rates, connecting a pair of nodes by using an optical path. Each *WCH* is defined by a sequence of triples {link [fiber (wavelength)]}. In real transmission systems, the number of *WCHs* multiplexed onto a single optical fiber is constrained. In order to fulfil traffic demands, the number of available optical fibers on an optical link is assumed unconstrained. The wavelength assignment should be done in such a way to avoid a space (fiber), wavelength, or time conflict between pairs of triples.

From the availability reasons, the path protection scenario is assumed. Each *WCH* could be carried by a primary path (P_i), the first shortest path used in faulty free condition, or by its spare path (S_i), the second shortest independent path used in the faulty condition of any element on the primary path.

In this analysis, the following assumptions are made: A *WCH* uses a single wavelength along all fibers on its route. Primary and spare *WCHs* could be assigned to different wavelengths.

The correctness of wavelength assignment could be checked according to the following rule:

- Two *WCHs* could be assigned to the same wavelength if they are mutually independent (I), or disjoint (D). Two *WCHs* are defined as mutually independent if they are carried by the paths that have no fiber in common. Two *WCHs* are disjoint as events, if both can not occur at the same time under assumption of a single element failure.

Under proposed protection scenario with single failure tolerance assumptions, the previous rule has the following consequences:

- Two primary paths are never disjoint.
- A primary path and its spare path are always independent and disjoint.
- A P_x and a S_y are disjoint and independent, if $P_x \subseteq P_y$.
- Two spare paths are disjoint if their primary paths are independent.

An example on Figure 1 shows the relationship between *WCHs* in sense of independence and disjointedness. Two pairs of *WCHs* connect node pairs A,C and B,C respectively, by using primary and spare paths. In this case the same wavelength could be assigned to all *WCHs*, because P_x and P_y are independent, and S_x and S_y are disjoint under single failure assumption.

Figure 1 An example of independent and disjoint wavelength channels

In order to minimize the total fiber length, the minimization is done in two steps:

- (1) Wavelengths are assigned to all WCHs.
- (2) The fiber-wavelength assignment for each optical link is done on the following basis: a WCH w_k with the wavelength λ_i is assigned to the first fiber
 - (a) on which λ_i is not occupied at all, or
 - (b) if the appearance of w_k is disjoint to the appearance of all already assigned WCHs w_j , $j \neq k$, which have wavelength λ_j .

In optimization procedure the following formulas were used:

$$f = \sum_{k=1}^E \left[F_k l_k + \alpha \frac{1}{UF_k} \right] \quad (1)$$

where f is the goal function to be minimized, E is the number of links in the network, F_k is the number of optical fibers on the optical link k , l_k is the length of the link k , w_k is the number of used wavelength channels on the link k , and α is real constant which determines the contribution size of utilization factor UF_k to goal function, for each link k . The utilization factor UF for entire network, which shows the fraction of total network capacity occupied by assigned WCHs, can be calculated by following expression:

$$UF = \frac{1}{E} \sum_{k=1}^E UF_k = \frac{1}{E} \sum_{k=1}^E \frac{w_k}{F_k l_k} \quad (2)$$

3 APPLICATION OF GENETIC ALGORITHM AND SIMULATED ANNEALING

Both GA [Goldberg] and SA [Aarts] belong to the class of general heuristic algorithms rooted in natural processes.

A modified simple GA [Goldberg] was used with the following parameters: one-point crossover, tournament selection technique, population size=100, crossover probability=0.6, mutation probability=0.01, and elitism.

In k th iteration of used SA algorithm, the temperature, as a control parameter, is decreased according to the following rule $c_k = \alpha c_{k-1}$. The number of examined solutions increases according to the following

40 Part Two: Wavelength conversion and assignment

formula $L_k = L_{k-1}/\beta^{0.1}$. The actual number of transitions executed in k th iteration is $L_k^* = \min_k\{L_k, L_{max}\}$, where L_{max} is the maximum number of accepted transitions.

The values of constants defining cooling schedule are as follows: $\alpha=0.95$, $\beta=1.01$, $c_0=300$, $L_0=200$, and $L_{max}=100$.

In *GA* and *SA*, the solutions are encoded as arrays of integers, where each integer specifies a wavelength of corresponding *WCH* using $\log_2 N_\lambda$ bits per each integer. Figure 2 shows an example of coding 5 *WCH*s with maximum number of $N_\lambda=4$ wavelengths.

1	0	1	1	0	0	1	0	0	1
λ_3		λ_4		λ_1		λ_3		λ_2	
<i>WCH</i> 1		<i>WCH</i> 2		<i>WCH</i> 3		<i>WCH</i> 4		<i>WCH</i> 5	

Figure 2 Solution coding in *GA* and *SA*

If the total number of *WCH*s in a network is N_{WCH} then the number of all potential solutions is

$$N_{TOT} = 2^{N_{WCH} \times \beta \times \log_2(N_\lambda)}. \quad (3)$$

The factor β depends if the primary and its spare path have the same wavelength ($\beta=1$), or the primary and its spare path can have different wavelengths ($\beta=2$).

4 WAVELENGTH ASSIGNMENT AS COLORING PROBLEM

In order to decrease very high complexity of wavelength assignment problem independence/disjointedness tests (*I/D* tests) are used, as defined in Chapter 2. The results of *I/D* tests can be represented by a *wavelength relationship graph WRG*. Each node in the *WRG* represents a *WCH* to which a wavelength should be assigned. A branch between a pair of nodes represents the fact that these nodes can not be assigned to the same wavelength. The problem of optimal wavelength assignment - how to assign wavelengths to *WCH* using minimal number of wavelengths - could be transformed to the graph coloring problem, where one should color the *WRG*, using minimal number of colors. Every regular graph coloring gives a regular solution of wavelength assignment problem, as compared to *GA* or *SA*, where a very big fraction of evaluated solutions are irregular. In searching for optimal graph coloring an *NP*-complete problem should be solved. In searching for a quasi-optimal graph coloring we use simple heuristic algorithm [Welsh, Powell].

- (1) In iteration k of algorithm, an uncolored node with highest node degree is colored by the color (wavelength) k . In the same iteration, additionally, all uncolored nodes, not neighboring to k -colored nodes, are colored, step-by-step, by the color k as well.

Figure 3 shows an example of wavelength assignment in a *WDM* network with 4 nodes and 5 links. Each link has 2 fibers for both directions. Each node pair is connecting by 2 *WCH*s, primary *P*, and spare *S* (see Table 1). The results of wavelength assignment by using wavelength relationship graph and simple coloring algorithm are presented in Table 1, as well.

Figure 3 An example network and its wavelength relationship graph (WRG) for the routing arrangement as mentioned in Table 1

Table 1 Wavelength assignment results for example network

Node pairs	Primary (P) WCHs	Links	λ	Spare (S) WCHs	Links	λ
<i>a b</i>	1	<i>A</i>	λ_1	2	<i>EB</i>	λ_1
<i>a c</i>	3	<i>D</i>	λ_1	4	<i>EC</i>	λ_1
<i>a d</i>	5	<i>E</i>	λ_4	6	<i>AB</i>	λ_4
<i>b c</i>	7	<i>AD</i>	λ_2	8	<i>BC</i>	λ_3
<i>b d</i>	9	<i>B</i>	λ_2	10	<i>AE</i>	λ_3
<i>c d</i>	11	<i>C</i>	λ_2	12	<i>DE</i>	λ_2

5 COMPARISON OF WAVELENGTH ASSIGNMENT RESULTS

The wavelength assignment procedure was carried out for a core part of the European Optical Network, a case study developed within the European Commission project COST 239 "Ultra-high capacity optical transmission networks" (Figure 4). The network consists of 11 nodes. The total traffic requirements are fulfilled by 75 WCHs, each 10 Gbit/s. The path protection scenario is assumed.

The results are presented in Table 2. The comparison is done for GA, SA, and GC approaches, taking into account different numbers of WCHs per fiber N_λ .

Figure 4 A core part of the European Optical Network – a case study COST 239

Table 2 Comparison of wavelength assignment results for the case study

	$N_\lambda = 4$			$N_\lambda = 8$		
	<i>GA</i>	<i>SA</i>	<i>GC</i>	<i>GA</i>	<i>SA</i>	<i>GC</i>
$\max_k \{F_k(i)\}$	12	14	10	10	12	6
$\sum_k F_k(i)$	178	190	158	134	150	92
$\sum_k w_k(i)$	500	502	472	542	504	482
<i>UF</i>	0.702	0.637	0.716	0.491	0.417	0.634
<i>TFL (km)</i>	91	97	84	71	79	49
	400	560	820	710	360	780

6 CONCLUSION

Two general heuristic search techniques, *GA* and *SA*, were applied in solving the wavelength assignment problem for the case study. Both techniques inherently do not use any additional knowledge about the problem. On the other hand, in the proposed approach the wavelength assignment is transformed to the graph-coloring problem, by using a great amount of the knowledge about the case. The determinism introduced produced better optimization results in a shorter running time. An analysis of searching results shows that *SA* is more sensitive to the values of control parameters (cooling schedule) than *GA* (crossover and mutation probability). Careful adjustment of the control parameters and additional experiments could improve optimization results in *GA* and *SA*, but it seems that a hybrid approach, where first independence/disjointedness tests are performed and then *GA* or *SA* are used in graph coloring, with a goal to minimize the total fiber length in the network.

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8 BIOGRAPHY

Branko Mikac was born in 1947, Gospic, Croatia. He received his B.Sc., M.Sc. and Ph.D. in electrical engineering from the Faculty of Electrical Engineering, University of Zagreb, Croatia, in 1970, 1980 and 1986, respectively. From 1974, he is with the Faculty. His research and lecture interests include transmission systems and reliability of telecommunication systems. He is a member of IEEE and Croatian Telecommunication Society. He is involved in project COST 239 "Ultra-high Capacity Optical Transmission Networks".

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