

A Multi-Objective Solution Applying MOEA in Optical Networks

Yezid Donoso, Carolina Alvarado, Alfredo Perez, Ivan Herazo
Computer Science Department
Universidad del Norte, Barranquilla, Colombia
{ydonoso, calvarado, perezaj}@uninorte.edu.co

Abstract: - This paper shows the solution of a multiobjective scheme for multicast transmissions in MPLS networks with a GMPLS optical backbone using evolutive algorithms. It has not been showed models that optimize one or more parameters integrating these two types of networks. Because the proposed scheme is a *NP-Hard* problem, an algorithm has been developed to solve the problem on polynomial time. The main contributions of this paper are the proposed mathematical model and the algorithm to solve it.

Key-Words: - MPLS, GMPLS, Multicast, Multiobjective Optimization, Evolutionary Algorithms

I. INTRODUCTION

The most recent applications developed to work on the Internet, have increased the necessity to send information from a sender to multiple destinations (Multicast) with certain *quality of service* parameters such as maximum packets delay, the cost and the number of packets that can be discarded and others parameters, without affecting the quality of the transmission. Moreover, when the transmission is made over optical networks, it is necessary to guaranty other quality parameters such as attenuation, delay and the number of wavelengths used. MPLS is a connection-oriented routing service that is considered as a layer between the Link and Network layers, and it is not a routing protocol by itself. GMPLS (Generalized Multiprotocol Label Switching) extends MPLS to provide the control plane (signaling and protocol) for devices that switch on any of these domains: packets, time, wavelength and distance. The objective of this paper is to present an optimization model for optimizing simultaneously the fiber attenuation, the delay and the number of wavelengths used for the multicast transmission on MPLS networks passing through a GMPLS optical backbone. For optimizing the model, the multiobjective evolutionary algorithm SPEA 2[1] (Strength Pareto Evolutionary Algorithm version 2) will be used.

II. RELATED WORK

In [2] Hua *et al.* formulate the problem of routing and wavelengths assignments on GMPLS networks as a Markov decision problem, with the objective of bringing service differentiation and a dynamical resource assignment.

In [3] Hwang *et al.* propose a routing scheme and a dynamical wavelength assignation using fuzzy logic in IP with GMPLS over DWDM networks, with the objective of improving the transmission quality on these networks. In [4] the authors describe different architectonic alternatives for the integration of IP and DWDM networks using MPLS (Multiprotocol Lambda Switching). In [5] Medrano *et al.* present an optimization model applied to the MPLS networks scheduling, which assign LSPs based on the capacity and the network architecture. In [7] Muñoz *et al.* propose a signaling protocol based on GMPLS for unidirectional ring networks that allow to have a global information of the wavelength resource without any routing assignation protocol when providing bidirectional connections. In [8] Yin Y. and Kuo Geng-Shen (G.S) developed an improvement of the wavelength assignation called label distribution in GMPLS. In [9] to [12] Donoso *et al.* propose different works about the multiobjective traffic engineering schema using different distribution trees to several multicast flows. In [13] Prathombutr, shows a series of reconfigurations corresponding to a series of changes in traffic demand matrices, therefore present a complete reconfiguration model applicable to any kind of traffic.

III. OPTIMAL MULTICAST ROUTING IN GMPLS AND MPLS NETWORKS.

For the developing of this paper, it has been considered a network topology as the one shown on Figure 1, which a GMPLS network is the core of the network. This network is integrated to different MPLS networks that provide the connection on the different borders. The multicast transmission is made from a source node in a MPLS network to a set of nodes in different MPLS networks passing through a GMPLS network as shown on Figure 1. The problem of minimizing the number of wavelengths (λ), the delay and the maximum attenuation on fiber for the multicast networks described before, is formulated as follows.

The network is modeled as a directed graph G , where N is the set of nodes, E is the number of non optical links MPLS and OE the set of optical links. In Figure 1, the link (dxc_i, dxc_j) belongs to E , and link (oxc_i, oxc_j) belongs to OE. The number of nodes is denoted as n , $n = |N|$. Let $s \in N$ be the source node (ingress node), T the set of egress nodes and $t \in T$ an egress node. Let dxc_i be the i^{th} that node that supports IP with MPLS. Let $(dxc_i, dxc_j) \in E$ the link from the dxc_i node to the node dxc_j .

Let oxc_i , the i^{th} node that supports GMPLS. Let $(oxc_i, oxc_j) \in OE$ the link from node oxc_i to node oxc_j . Let $(dxc_i, oxc_j) \in E$ the link from node dxc_i to the node oxc_j . Let $(oxc_i, dxc_j) \in E$ the link from node oxc_i to the node dxc_j . Let $f \in F$, a multicast flow where F is the set of flows and T_f is the set of egress nodes for the f flow. $|F|$ denotes the number of flows and $T = \bigcup_{f \in F} T_f$. Let $v_{dxc_i, v_{dxc_j}}$ be the delay on the link (dxc_i, dxc_j) , $v_{dxc_i, v_{oxc_j}}$ the delay on the link (dxc_i, oxc_j) , $v_{oxc_i, v_{oxc_j}}$ the delay on the link (oxc_i, oxc_j) and $v_{oxc_i, v_{dxc_j}}$ the delay on the link (oxc_i, dxc_j) .

The variable X_{dxc_i, dxc_j}^{lft} , represents the utilization of the MPLS link (dxc_i, dxc_j) for sending the flow f using the l label for the egress node t . This variable can take two values: 1 if it is used or 0 if it is not.

The variable X_{oxc_i, dxc_j}^{lft} , represents the utilization of the MPLS link (oxc_i, dxc_j) for sending the flow f using the l label for the egress node t .

The variable $Y_{oxc_i, oxc_j}^{\lambda lft}$ represents the utilization of the link (oxc_i, oxc_j) for sending the flow f on the label l with wavelength λ for the egress node t . This variable also can take two values: 1 or 0. C_{dxc_i, dxc_j} represents the capacity of each MPLS link (dxc_i, dxc_j) ; C_{dxc_i, oxc_j} , represents the capacity of each MPLS link (dxc_i, oxc_j) ; C_{oxc_i, dxc_j} , represents the capacity of each MPLS link (oxc_i, dxc_j) , and $CO_{oxc_i, oxc_j}^\lambda$ represents the capacity of the wavelength λ on each link (oxc_i, oxc_j) . $M_{-}Y_{oxc_i, oxc_j}$ represents the maximum number of wavelengths λ in on the link (oxc_i, oxc_j) . As bw_f is denoted the bandwidth consumed by the flow f .

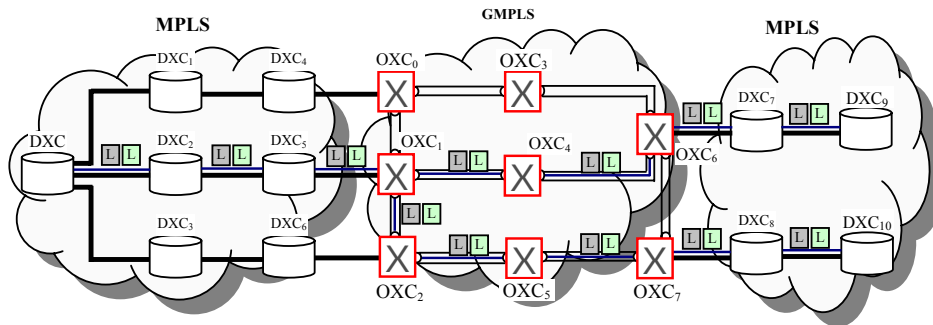


Fig. 1. Multicast transmission from a MPLS network to others MPLS through a GMPLS network.

Therefore, the problem is

$$Min(z) = \{f_1, f_2, f_3\} \text{ where}$$

$f_1 = \sum_{\lambda \in \Lambda} \max \left(Y_{oxc_i, oxc_j}^{\lambda lft} \right)_{l \in L, t \in T_f, f \in F, (oxc_i, oxc_j) \in OE}$	(number of wavelengths)
$f_2 = \max \left(\left(10^{-A_{oxc_i, oxc_j} * D_{oxc_i, oxc_j} / 10} * P(i) \right)_{(oxc_i, oxc_j) \in OE, \lambda \in \Lambda} \right)_{l \in L, t \in T_f, f \in F}$	(maximum attenuation)

$$\begin{aligned}
 f_3 = & \sum_{f \in F} \sum_{(dxc_i, dxc_j) \in E} v_{(dxc_i, dxc_j)} * \max \left(X_{dxc_i, dxc_j}^{lft} \right)_{l \in L, t \in T} + \\
 & \sum_{f \in F} \sum_{(dxc_i, oxc_j) \in E} v_{(dxc_i, oxc_j)} * \max \left(X_{dxc_i, oxc_j}^{lft} \right)_{l \in L, t \in T} + \\
 & \sum_{f \in F} \sum_{(oxc_i, oxc_j) \in E} v_{(oxc_i, oxc_j)} * \max \left(Y_{oxc_i, oxc_j}^{\lambda lft} \right)_{\lambda \in \Lambda, l \in L, t \in T} + \\
 & \sum_{f \in F} \sum_{(oxc_i, dxc_j) \in E} v_{(oxc_i, dxc_j)} * \max \left(X_{oxc_i, dxc_j}^{lft} \right)_{l \in L, t \in T} + \\
 & \sum_{f \in F} \sum_{(dxc_i, dxc_j) \in E} v_{(dxc_i, dxc_j)} * \max \left(X_{dxc_i, dxc_j}^{lft} \right)_{l \in L, t \in T}
 \end{aligned}$$

(total delay)

Subject to

Constraints	Mathematical Expression	Physical Meaning
1	$\sum_{(dxc_i, dxc_j)} X_{dxc_i, dxc_j}^{lft} = 1, t \in T_f, f \in F, i = s$	Assures that the total flow that come out from the ingress node to the set of the egress nodes $t \in T_f$, be one
2	$\sum_{(dxc_i, dxc_j)} X_{dxc_i, dxc_j}^{lft} = -1, i, t \in T_f, f \in F$	Assures that the total flow that ingress to a egress node $t \in T_f$, be one.
3	$\sum_{(dxc_k, oxc_i) \in E} \sum_{t \in T_f} \sum_{f \in F} \sum_{l \in L} X_{dxc_k, oxc_i}^{lft} = \sum_{(oxc_i, oxc_j) \in OE} \sum_{t \in T_f} \sum_{f \in F} \sum_{l \in L} \sum_{\lambda \in \Lambda} Y_{oxc_i, oxc_j}^{\lambda lft}, \forall (oxc_i, oxc_j) \in OE, (dxc_i, oxc_j) \in E$	Assures that the sum of the labels that enters into a <i>oxc</i> node that come from a <i>dxc</i> node, be equal to the number of labels that come out from that <i>oxc</i> node (through its λ s).
4	$\sum_{(oxc_j, oxc_k) \in OE} \sum_{t \in T_f} \sum_{f \in F} \sum_{l \in L} \sum_{\lambda \in \Lambda} Y_{oxc_j, oxc_k}^{\lambda lft} = \sum_{(oxc_k, dxc_m) \in E} \sum_{t \in T_f} \sum_{f \in F} \sum_{l \in L} X_{oxc_k, dxc_m}^{lft}, \forall (oxc_j, oxc_k) \in OE, (oxc_k, dxc_m) \in E$	Assures that the number of labels that come out from a <i>oxc</i> node to a <i>dxc</i> node, be equal to the number of nodes that ingress to a <i>dxc</i> node.
5	$\sum_{(oxc_i, oxc_j) \in OE} \sum_{t \in T_f} \sum_{f \in F} \sum_{l \in L} \sum_{\lambda \in \Lambda} Y_{oxc_i, oxc_j}^{\lambda lft} = \sum_{(oxc_j, oxc_k) \in OE} \sum_{t \in T_f} \sum_{f \in F} \sum_{l \in L} \sum_{\lambda \in \Lambda} Y_{oxc_j, oxc_k}^{\lambda lft}, \forall (oxc_i, oxc_j), (oxc_j, oxc_k) \in OE$	Assures that the number of labels that come in to a <i>oxc</i> node, be equal to the labels that come out from it.
6	$\sum_{(dxc_h, dxc_i) \in E} \sum_{t \in T_f} \sum_{f \in F} \sum_{l \in L} X_{dxc_h, dxc_i}^{lft} = \sum_{(dxc_i, dxc_j) \in E} \sum_{t \in T_f} \sum_{f \in F} \sum_{l \in L} X_{dxc_i, dxc_j}^{lft}, \forall (dxc_h, dxc_i), (dxc_i, dxc_j) \in E$	Guaranties that the number of labels that come into a <i>dxc</i> node, be equal to the number of labels that come out from it.
7	$\sum_{\lambda \in \Lambda} \max \left(Y_{oxc_i, oxc_j}^{\lambda lft} \right)_{l \in L, t \in T, \lambda \in \Lambda} \leq M - Y_{oxc_i, oxc_j}, \forall (oxc_i, oxc_j) \in OE$	Assures that the number of wavelengths used in the (oxc_i, oxc_j) node is not greater than the maximum number of wavelengths allowed for that optical link.
8	$\sum_{f \in F} \max \left(Y_{oxc_i, oxc_j}^{\lambda lft} \right)_{l \in L, t \in T, \lambda \in \Lambda} * bw_f \leq CO_{oxc_i, oxc_j}^{\lambda}, \forall (oxc_i, oxc_j) \in OE$	Assures that the sum of bandwidths transmitted over the different λ s in the link (oxc_i, oxc_j) is less than or equal to the capacity of a wavelength on that link.

9	$\sum_{f \in F} \max (X_{dxc_i, dxc_j}^{lft})_{l \in L, t \in T} * bw_f \leq C_{dxc_i, dxc_j},$ $\forall (dxc_i, dxc_j) \in E$	Assures that the sum of bandwidths transmitted over the MPLS link (dxc_i, dxc_j) is less than or equal to the capacity of the link.
10	$\sum_{f \in F} \max (X_{dxc_i, oxc_j}^{lft})_{l \in L, t \in T} * bw_f \leq C_{dxc_i, oxc_j},$ $\forall (dxc_i, oxc_j) \in E$	Assures that the sum of bandwidths transmitted over the MPLS link (dxc_i, oxc_j) is less than or equal to the capacity of the link.
11	$\sum_{f \in F} \max (X_{oxc_i, dxc_j}^{lft})_{l \in L, t \in T} * bw_f \leq C_{oxc_i, dxc_j},$ $\forall (oxc_i, dxc_j) \in E$	Assures that the sum of bandwidths transmitted over the MPLS link (oxc_i, dxc_j) is less than or equal to the capacity of the link.
12	$X_{dxc_i, dxc_j}^{lft} \in Z, [0,1]$	Indicates that value of the X_{dxc_i, dxc_j}^{lft} variable must be 0 or 1.
13	$X_{dxc_i, oxc_j}^{lft} \in Z, [0,1]$	Indicates that value of the X_{dxc_i, oxc_j}^{lft} variable must be 0 or 1.
14	$X_{oxc_i, dxc_j}^{lft} \in Z, [0,1]$	Indicates that value of the X_{oxc_i, dxc_j}^{lft} variable must be 0 or 1.
15	$Y_{oxc_j, oxc_k}^{lft} \in Z, [0,1]$	Indicates that value of the Y_{oxc_j, oxc_k}^{lft} variable must be 0 or 1.

Due to the variables Y_{oxc_i, oxc_j}^{lft} are binaries and more than one label can pass on a λ wavelength depending on its capacity, \max appears on f_l . Therefore, it is just necessary to count one wavelength on the total sum if two or more labels use the same wavelength; nevertheless

more than one label can pass through that λ . Figure 2 illustrates this situation. The labels $L1, L2$ and $L3$ ingress on the oxc_1 node, $L1$ and $L2$ arrive to the node oxc_2 using λ_1 , but $L3$ leave oxc_1 using λ_2 . As it can be seen, two different wavelengths are used and are counted.

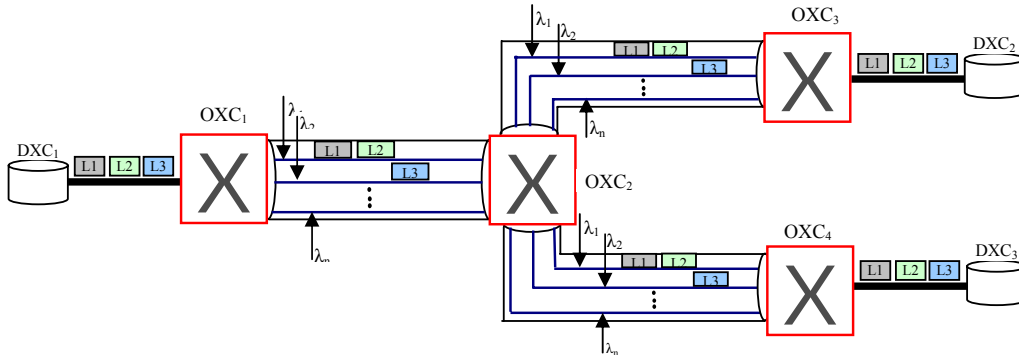


Fig 2. Number of wavelengths used on a multicast transmission.

In $f_2, 10^{-A_{ij} * D_{ij} / 10} * P(i)$, stands for the attenuation on the optical fiber.

Because there are different link types used, the calculation of the total delay must be done by segments.

Therefore, in f_3

$$\sum_{f \in F} \sum_{(dxc_i, dxc_j) \in E} v_{(dxc_i, dxc_j)} * \max(X_{dxc_i, dxc_j}^{lft})_{l \in L, t \in T}$$

represents the total delay between two non optical nodes,

$$\sum_{f \in F} \sum_{(dxc_i, oxc_j) \in E} v_{(dxc_i, oxc_j)} * \max(X_{dxc_i, oxc_j}^{lft})_{l \in L, t \in T}$$

represents the total delay over a non optical link,

$$\sum_{f \in F} \sum_{(oxc_i, oxc_j) \in E} v_{(oxc_i, oxc_j)} * \max(Y_{oxc_i, oxc_j}^{lft})_{\lambda \in \Lambda, l \in L, t \in T}$$

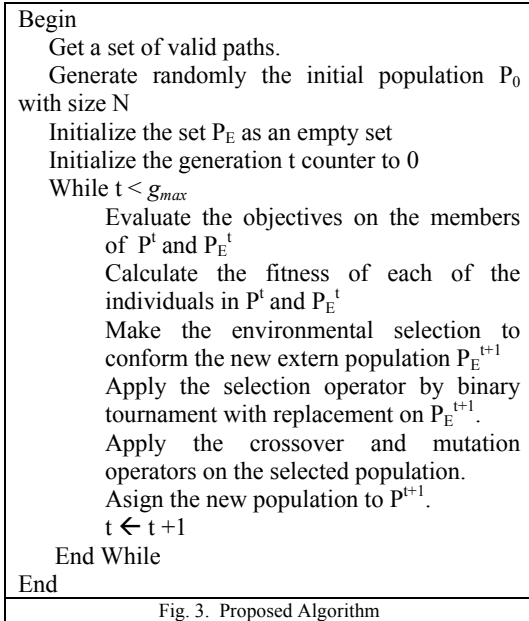
represents the total delay over an optical link,

$$\sum_{f \in F} \sum_{(oxc_i, dxc_j) \in E} v_{(oxc_i, dxc_j)} * \max(X_{oxc_i, dxc_j}^{lft})_{l \in L, t \in T}$$

represents the total delay over a non optical link.

IV. APPLICATION OF THE PROPOSED ALGORITHM FOR THE PROBLEM SOLUTION

This section shows the evolutionary algorithm SPEA 2 as the metaheuristic used for solving the multiobjective problem described above. The algorithm receives as parameters the network topology, the ingress node s , the set of egress nodes T , and the flow f . Figure 3, shows the general proposed algorithm for solving the multiobjective optimization problem.



A. Chromosome Representation

As we want to find the trees with the minimum values of attenuation and number of wavelengths it is necessary to define how the chromosome is going to be represented (multicast tree). Figure 4, shows the chromosome representation used on this paper. The chromosome is

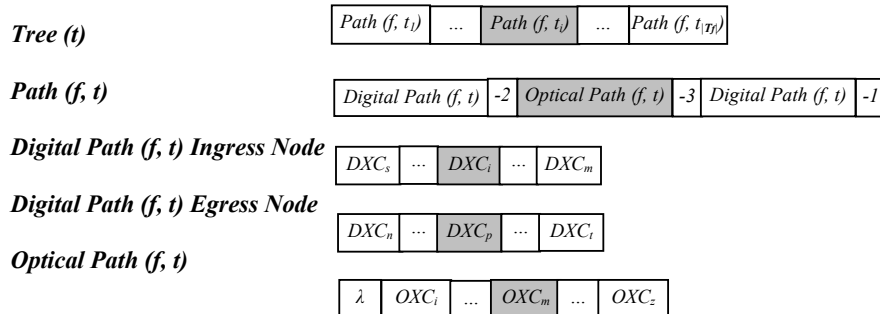


Fig 4. Chromosome Representation

composed by a multicast tree that is conformed by the routes from the source to each destination. Each route is conformed by a segment of digital path that begins on the source, an optical segment and a digital segment and ends on the destination node. The pass from a digital segment to an optical is represented with a -2, the pass from an optical to a digital node is represented with a -3, and the end of the path is marked with a -1

B. Generation of Initial Population

A previous search of paths from the source to each of the destination nodes $t \in T_f$ is made using a *BFS* search. After, the individual is created choosing at random a route for each of the destination nodes. If the constructed individual exists on the initial population it is discarded and a new one is constructed. The process is repeated until the population size equals to N (N is the size of the population).

C. Crossover

Two crossover operators were used. The first one chooses a randomly a locus on the chromosome and the crossover is made as shown on figure 5. The second crossover operator, chooses a path from a destination on the first chromosome, then checks on the second chromosome if they have a node in common (different from the source) and if it is true, the operator makes the crossover as it is shown on figure 6.

D. Mutation

The mutation is direct and it works choosing at random the path that is going to be mutated. This path is replaced by another path to the same destination chosen randomly. Figure 7 shows the mutation operator.

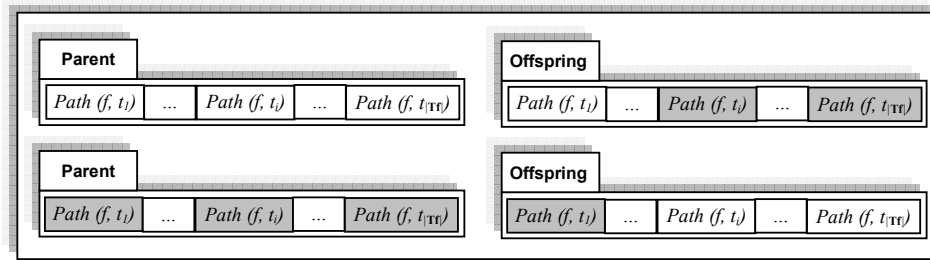


Fig. 5. First Crossover operator

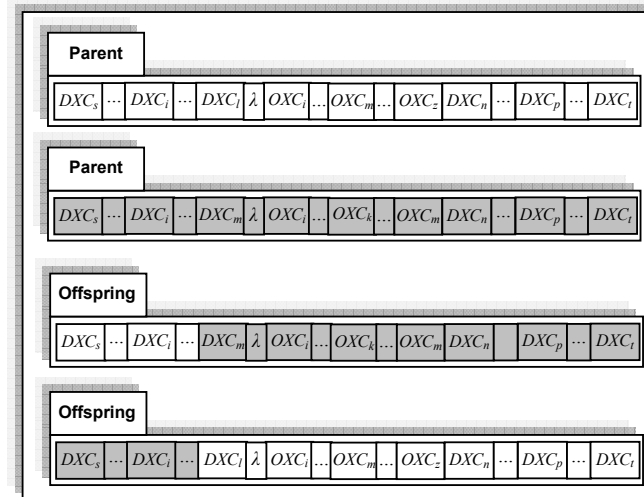


Fig. 6. Second Crossover operator.

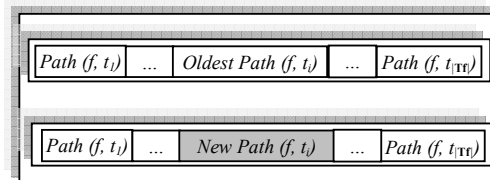


Fig. 7. Mutation operator

V. EXPERIMENTATION AND RESULTS

A. Design of the experiment

The network topology has 28 nodes, 14 non optical nodes and 14 optical nodes (NSF Backbone). The Optimal Pareto front for each of the flows for the different destination sets, was constructed using the best non dominated individuals (best individuals under the Pareto approach) on the 30 executions of the algorithm.

For each destination set, the average execution time, and the maximum, minimum and average values of the wavelength number, the attenuation and total delay

functions were calculated. The generational distance to the Optimal Pareto front of each destination set was calculated for each execution. The generational distance

can be calculated as follows $DG = \frac{\sqrt{\sum_{i=1}^N d_i^2}}{GVND}$, where d_i is

the distance between every vector in the Pareto front obtained and the vector nearest in the real Pareto front and $GVND$ stands for the cardinality of the Pareto front of the execution. Spread to the Optimal Pareto Front of each destination set was calculated for each execution. Spacing (S) can be calculated as follows $S = \sqrt{\frac{1}{|Q|} \sum_{i=1}^{|Q|} (d_i - \bar{d})^2}$, where

$$d_i = \min_{k \in Q \wedge k \neq i} \sum_m^M |f_m^i - f_m^k| \quad \text{and} \quad \bar{d} = \sum_{i=1}^{|Q|} \frac{d_i}{|Q|}$$

The population size was 50 chromosomes, the size of the

external population was 25, the maximum number of generations (g_{max}) was 50, $P_{crossover_individuals}$ was 0.4, $P_{crossover_paths}$ was 0.4 and $P_{mutation}$ was 0.1.

B. Results

Table I and II shows the minimum, maximum, average values and standard deviation for the different flows on the 10-node destination set and 9-node destination set respectively. With respect to the minimum number of used wavelengths is one until the 6-node destination set. From the 7-node to the 10-node destination sets, the value augment to two. The minimum attenuation from the 4-node destination set tends toward the value of 3,26 for different flows and different destination set. However, on

some cases we found values lower than 3,26 and it is explained by the apparition of individuals with unutilized links by the common of the individuals gotten by each execution of the algorithm. The maximum attenuation value from the 4-destination set remains constant with the value of 7,94 which make us conclude that this is the maximum attenuation on the network as it did not change by the consecutive executions of the algorithms. The Table III shows the average generational distance for each flow on the different destination sets. A light decrement of this measure for the different flows it is seen until the 5-node destination set. Table IV shows the average spacing for each flow on the different destination sets. A strong increment of S its seen from 2 to 3 node destination set and a light increment is seen since 3-node destination set.

TABLE I
10-NODE DESTINATION SET RESULTS

	MIN			MAX			AVG			DEV		
	λ_s	AT	DL	λ_s	AT	DL	λ_s	AT	DL	λ_s	AT	DL
10% total flow	2,00	3,15	465,00	9,00	7,94	792,00	5,10	5,24	574,58	1,42	1,40	58,39
25% total Flow	2,00	3,26	494,00	9,00	7,94	759,00	5,28	5,81	589,91	1,41	1,37	45,58
50% total Flow	2,00	3,26	501,00	9,00	7,94	771,00	5,43	5,54	593,14	1,50	1,41	45,99
75% total Flow	2,00	3,26	496,00	9,00	7,94	753,00	5,22	5,39	586,27	1,45	1,51	46,91
100% total Flow	2,00	3,26	480,00	9,00	7,94	807,00	5,22	5,80	590,54	1,36	1,46	46,04

TABLE II
9-NODE DESTINATION SET RESULTS

	MIN			MAX			AVG			DEV		
	λ_s	AT	DL	λ_s	AT	DL	λ_s	AT	DL	λ_s	AT	DL
10% total flow	2,00	3,26	433,00	8,00	7,94	662,00	4,93	5,58	523,25	1,36	1,50	40,75
25% total Flow	2,00	3,26	430,00	8,00	7,94	766,00	4,87	5,58	520,58	1,27	1,47	51,41
50% total Flow	2,00	3,26	417,00	8,00	7,94	663,00	4,90	5,65	513,39	1,32	1,65	39,73
75% total Flow	2,00	3,26	417,00	8,00	7,94	673,00	4,93	5,57	513,08	1,31	1,66	46,72
100% total Flow	2,00	3,26	431,00	8,00	7,94	694,00	4,99	5,62	514,75	1,29	1,56	49,32

TABLE III
AVERAGE GENERATIONAL DISTANCE

	2D	3D	4D	5D	6D	7D	8D	9D	10D
10% total flow	8,64	5,24	2,01	3,11	5,82	11,26	8,35	7,10	6,19
25% total Flow	9,91	6,17	5,37	2,07	5,00	11,67	3,41	6,59	4,95
50% total Flow	7,18	5,67	2,64	4,91	11,47	8,38	5,34	3,67	2,75
75% total Flow	11,22	13,67	5,43	5,97	4,92	10,17	3,61	4,07	2,53
100% total Flow	9,00	9,24	7,43	4,17	2,92	4,60	6,40	4,04	6,04

TABLE IV
Average Spacing

	2D	3D	4D	5D	6D	7D	8D	9D	10D
10% total flow	3,67	13,80	23,39	24,68	28,77	25,30	23,55	30,90	39,49
25% total flow	3,84	18,16	20,59	23,28	28,12	26,76	24,51	30,06	46,19
50% total flow	3,71	15,83	23,34	24,34	25,34	27,24	26,98	36,01	40,79
75% total flow	3,56	19,39	22,25	25,17	26,53	26,46	28,18	33,46	36,90
100% total flow	3,39	14,37	23,25	22,02	27,32	26,43	26,51	33,37	40,84

VI. CONCLUSIONS

A multiobjective optimization model scheme that minimizes simultaneously three functions has been proposed on this paper. To solve the problem the algorithm SPEA II was chosen because this algorithm has shown the best results for this kind of problem. The functions that intends to guaranty quality of service on this paper are number of used wavelengths, total delay and maximum link attenuation.

The increment of the destinations sets size produced an augmentation, in general terms, of the values of the optimized functions, with the exception of the minimum wavelengths used and the minimum and maximum attenuation in the network used, which value was 7,94.

An increase on the average execution time was observed when the size of the destinations set augmented. This increase was expected because as the size of the destinations augments, so the search space does.

REFERENCE

- [1] Zitzler, E.; Laumanns M. and Thiele L. SPEA2: Improving the Strength Pareto Evolutionary Algorithm. *Computer Engineering and Networks Laboratory. Report No. 103*. Swiss Federal Institute of Technology (ETH) 2000.
- [2] Yu Hua; Wei Xu; Chanle Wu, Routing and wavelength assignment in GMPLS networks. *Proceedings of the Fourth International Conference on Parallel and Distributed Computing, Applications and Technologies*, 2003, pp. 268 – 271.
- [3] I-Shyan Hwang; I-Feng Huang; Shin-Cheng Yu, Dynamic RWA scheme using fuzzy logic control (FLC RWA) on IP with GMPLS over DWDM networks. *2004 IEEE International Conference on Networking, Sensing and Control*, Vol. 2, 2004, pp.1049 – 1056.
- [4] Duresi A.; Chandhok N.,; Jagannathan R.; Jain R.; Seetharaman S.; Vinodkrishnan K.; IP over optical networks: a summary of issues, *IETF draft, July 2000*.
- [5] Medrano, M.S.; Trindade, M.B.; de Chaves, N.S.A.; Fernandez, M.D.; Filho, H.J.M., An optimization model for MPLS networks, *11th International Telecommunications Network Strategy and Planning Symposium*.2004, pp. 285 - 290.
- [6] Banerjee, N.; Sharan, S., A evolutionary algorithm for solving the single objective static routing and wavelength assignment problem in WDM networks. *Proceedings of International Conference on Intelligent Sensing and Information Processing*, 2004, pp. 13 – 18.
- [7] Muñoz, R.; Martinez, R.; Sorribes, J.; Junyent, G, Flooding global wavelength information through GMPLS RSVP-TE signaling in unidirectional ring-based networks. *2005 IEEE International Conference on Communications*, 2005. Vol. 3, 2005, pp. 1678 – 1682.
- [8] Yin Yong; Kuo, G.-S.; Label distribution in GMPLS-based wavelength-routed networks, *IEEE International Conference on Communications*, 2005.2005, Vol. 3, 2005, pp. 1697 – 1701.
- [9] Donoso, Y.; Fabregat, R.; Marzo J.L, A Multi-Objective Optimization Scheme for Multicast Routing: A Multitree Approach, *Telecommunication Systems*, Vol. 27, 2004, pp. 229 – 25.
- [10] Donoso, Y.; Fabregat, R.; Solano, F.; Marzo J.L.; Baran, B., Generalized multiobjective multitree model for dynamic multicast groups. *2005 IEEE International Conference on Communications*, 2005 Vol. 1, 2005, pp. 148 – 152.
- [11] Donoso, Y.; Fabregat, R.; Marzo, J.L., Multiobjective optimization model and heuristic algorithm for dynamic multicast routing, *11th International Telecommunications Network Strategy and Planning Symposium*. 2004, pp. 423 - 428.
- [12] Donoso, Y.; Fabregat, R. ; Marzo, J.L , Multi-objective optimization scheme for dynamic multicast groups, *9th International Symposium on Computers and Communications*, 2004. *Proceedings*. Vol. 2, 2004, pp. 1018 - 1023.
- [13] Prathombutr, P., Virtual Topology Reconfiguration in Wavelength-Routed Optical Networks, *2003 Dissertation in Software Architecture and Computer Networking*.