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Multiobjective Optimization for Multicast Transmissions on IP/MPLS Networks with an Optical GMPLS Backbone

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Abstract: - Different optimization models presented on literature show optimization schemes over MPLS or GMPLS networks. However, it has not been showed models that optimize one or more parameters integrating these two types of networks. In this paper a multiobjective scheme for multicast transmissions from a source node to a set of destination nodes in MPLS passing through a GMPLS optical backbone is shown. 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

1 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 (Strength Pareto Evolutionary Algorithm version 2) will be used.

2 Related Work

In [1] Hua *et al.* formulate the problem of routing and wavelengths assignations on GMPLS networks as a Markov decision problem, with the objective of bringing service differentiation and a dynamical resource assignment. In [2] 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 [3] the authors describe different architectonic alternatives for the integration of IP and DWDM networks using MPλS (Multiprotocol Lambda Switching). In [4] 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 [6] 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 [7] Yin Y. and Kuo Geng-Shen (G.S) developed an improvement of the wavelength assignation called label distribution in GMPLS. In [8] to [11] Donoso *et al.* propose different works about the multiobjective traffic engineering schema using different distribution trees to several multicast flows.

3. Optimal Multicast routing in GMPLS and MPLS networks.

For the developing of this paper, it has been considerated 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

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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] node that supports IP with MPLS. Let (dxc_i, dxc_j) ∈ 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) ∈ OE the link from node oxc_i to node oxc_j. Let (dxc_i, oxc_j) ∈ E the link from node dxc_i to the node oxc_j. Let (oxc_i, dxc_j) ∈ 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 $v_{dxc_i,} v_{dxcj}$ be the delay on the link (dxc_i, dxc_j), $v_{dxc_i,} v_{oxcj}$ the delay on the link (dxc_i, oxc_j), $v_{oxc_i,} v_{oxcj}$ the delay on the link (oxc_i, oxc_j) and $v_{oxc_i,} v_{doxcj}$ the delay on the link (oxc_i, dxc_j). The variable $X^{lft}_{dxc_i,dxc_j}$, 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 $X^{lft}_{oxc_i,dxc_j}$, 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 $Y^{\lambda lft}_{oxc_i,oxc_j}$ 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 $CO^{\lambda}_{oxc_i,oxc_j}$ 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 consummed by the flow f.

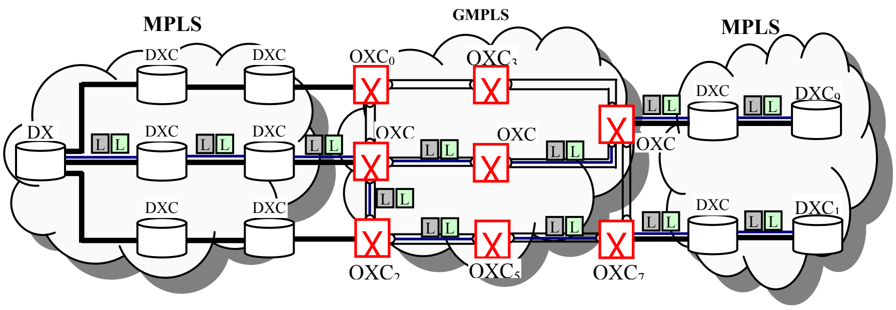

Fig. 1. Multicast transmission from a MPLS network to others MPLS through a GMPLS network.

Therefore, the problem is $Min(\mathbf{z})=\{ f_1 , f_2 , f_3 \}$ where

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

$f_3 = \sum_{f\in F}\sum_{(dxc_i,dxc_j)\in E} v_{(dxc_i,dxc_j)} * \max\left(X^{lft}_{dxc_i,dxc_j}\right)_{l\in L,t\in T} + \sum_{f\in F}\sum_{(dxc_i,oxc_j)\in E} v_{(dxc_i,oxc_j)} * \max\left(X^{lft}_{dxc_i,oxc_j}\right)_{l\in L,t\in T} + \sum_{f\in F}\sum_{(oxc_i,oxc_j)\in E} v_{(oxc_i,oxc_j)} * \max\left(Y^{\lambda lft}_{oxc_i,oxc_j}\right)_{\lambda\in\Lambda,l\in L,t\in T} + \sum_{f\in F}\sum_{(oxc_i,dxc_j)\in E} v_{(oxc_i,dxc_j)} * \max\left(X^{lft}_{oxc_i,dxc_j}\right)_{l\in L,t\in T} + \sum_{f\in F}\sum_{(dxc_i,dxc_j)\in E} v_{(dxc_i,dxc_j)} * \max\left(X^{lft}_{dxc_i,dxc_j}\right)_{l\in L,t\in T}$	(total delay)

Subject to

Constraints	**Mathematical Expression**	**Physical Meaning**
C1	$\sum_{(dxc_i,dxc_j)} X^{lft}_{dxc_i,dxc_j} = 1,\ t\in T_f, f\in F, i=s$	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
C2	$\sum_{(dxc_i,dxc_j)} X^{lft}_{dxc_i,dxc_j} = -1,\ i,t\in T_f, f\in F$	Assures that the total flow that ingress to a egress node $t \in T_f$, be one.
C3	$\sum_{(dxc_k,oxc_i)\in E}\sum_{t\in T_f}\sum_{f\in F}\sum_{l\in L} X^{lft}_{dxc_k,oxc_i} = \sum_{(oxc_i,oxc_j)\in OE}\sum_{t\in T_f}\sum_{f\in F}\sum_{l\in L}\sum_{\lambda\in\Lambda} Y^{\lambda lft}_{oxc_i,oxc_j},\ \forall (oxc_i,oxc_j)\in OE,\ (dxc_i,oxc_j)\in E$	Assures that the sum of the labels that enters into a *oxc* node that come from a *dxc* node, be equal to the number of labels that come out from that *oxc* node (through its λs).
C4	$\sum_{(oxc_j,oxc_k)\in OE}\sum_{t\in T_f}\sum_{f\in F}\sum_{l\in L}\sum_{\lambda\in\Lambda} Y^{\lambda lft}_{oxc_j,oxc_k} = \sum_{(oxc_k,dxc_m)\in E}\sum_{t\in T_f}\sum_{f\in F}\sum_{l\in L} X^{lft}_{oxc_k,dxc_m},\ \forall (oxc_j,oxc_k)\in OE,\ (oxc_k,dxc_m)\in E$	Assures that the number of labels that come out from a *oxc* node to a *dxc* node, be equal to the number of nodes that ingress to a *dxc* node.
C5	$\sum_{(oxc_i,oxc_j)\in OE}\sum_{t\in T_f}\sum_{f\in F}\sum_{l\in L}\sum_{\lambda\in\Lambda} Y^{\lambda lft}_{oxc_i,oxc_j} = \sum_{(oxc_j,oxc_k)\in OE}\sum_{t\in T_f}\sum_{f\in F}\sum_{l\in L}^{\lambda}\sum_{\lambda\in\Lambda}^{L} Y^{\lambda lft}_{oxc_j,oxc_k},\ \forall (oxc_i,oxc_j),(oxc_j,oxc_k)\in OE$	Assures that the number of labels that come in to a *oxc* node, be equal to the labels that come out from it.
C6	$\sum_{(dxc_h,dxc_i)\in E}\sum_{t\in T_f}\sum_{f\in F}\sum_{l\in L} X^{lft}_{dxc_h,dxc_i} = \sum_{(dxc_i,dxc_j)\in E}\sum_{t\in T_f}\sum_{f\in F}\sum_{l\in L} X^{lft}_{dxc_i,dxc_j},\ \forall (dxc_h,dxc_i),(dxc_i,dxc_j)\in E$	Guaranties that the number of labels that come into a *dxc* node, be equal to the number of labels that come out from it.
C7	$\sum_{\lambda\in\Lambda} \max\left(Y^{\lambda lft}_{oxc_i,oxc_j}\right)_{l\in Lt\in T,\lambda\in\Lambda} \le M\_Y_{oxc_i,oxc_j},\ \forall (oxc_i,oxc_j)\in OE$	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.
C8	$\sum_{f\in F} \max\left(Y^{\lambda lft}_{oxc_i,oxc_j}\right)_{l\in L,t\in T,\lambda\in\Lambda} * bw_f \le CO^{\lambda}_{oxc_i,oxc_j},\ \forall (oxc_i,oxc_j)\in OE$	Assures that the sum of bandwidths transmitted over the different λs in the link (oxc_i, oxc_j) is less than or equal to the capacity of a wavelength on that link.

C9	$\sum_{f \in F} \max\left(X^{lft}_{dxc_i, dxc_j}\right)_{l \in L, t \in T} * bw_f \leq C_{dxc_i, dxc_j}$, $\forall \left(dxc_i, dxc_j\right) \in E$	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.
C10	$\sum_{f \in F} \max\left(X^{lft}_{dxc_i, oxc_j}\right)_{l \in L, t \in T} * bw_f \leq C_{dxc_i, oxc_j}$, $\forall \left(dxc_i, oxc_j\right) \in E$	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.
C11	$\sum_{f \in F} \max\left(X^{lft}_{oxc_i, dxc_j}\right)_{l \in L, t \in T} * bw_f \leq C_{oxc_i, dxc_j}$, $\forall \left(oxc_i, dxc_j\right) \in E$	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.
C12	$X^{lft}_{dxc_i, dxc_j} \in Z, [0,1]$	Indicates that value of the $X^{lft}_{dxc_i, dxc_j}$ variable must be 0 or 1.
C13	$X^{lft}_{dxc_i, oxc_j} \in Z, [0,1]$	Indicates that value of the $X^{lft}_{dxc_i, oxc_j}$ variable must be 0 or 1.
C14	$X^{lft}_{oxc_i, dxc_j} \in Z, [0,1]$	Indicates that value of the $X^{lft}_{oxc_i, dxc_j}$ variable must be 0 or 1.
C15	$Y^{\lambda lft}_{oxc_j, oxc_k} \in Z, [0,1]$	Indicates that value of the $Y^{\lambda lft}_{oxc_j, oxc_k}$ variable must be 0 or 1.

Due to the variables $Y^{\lambda lft}_{oxc_i, oxc_j}$ are binaries and more than one label can pass on a λ wavelength depending on its capacity, *max* appears on f_1. 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 3 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.

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 $\sum_{f \in F} \sum_{(dxc_i, dxc_j) \in E} v_{(dxc_i, dxc_j)} * \max\left(X^{lft}_{dxc_i, dxc_j}\right)_{l \in L, t \in T}$ represents the total delay between two non optical nodes, $\sum_{f \in F} \sum_{(dxc_i, oxc_j) \in E} v_{(dxc_i, oxc_j)} * \max\left(X^{lft}_{dxc_i, oxc_j}\right)_{l \in L, t \in T}$ represents the total delay over a non optical link, $\sum_{f \in F} \sum_{(oxc_i, oxc_j) \in E} v_{(oxc_i, oxc_j)} * \max\left(Y^{\lambda lft}_{oxc_i, oxc_j}\right)_{\lambda \in \Lambda, l \in L, t \in T}$ represents the total delay over an optical link, $\sum_{f \in F} \sum_{(oxc_i, dxc_j) \in E} v_{(oxc_i, dxc_j)} * \max\left(X^{lft}_{oxc_i, dxc_j}\right)_{l \in L, t \in T}$ represents the total delay over an non optical link.

4 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 2, shows the general proposed algorithm for solving the multiobjective optimization problem

```
Begin
    Get a set of valid paths.
    Generate randomly the initial population P0 with size N
    Initialize the set PE as an empty set
    Initialize the generation t counter to 0
    While Que t < gmax
        Evaluate the objectives on the members of Pt and PE^t
        Calculate the fitness of each of the individuals in Pt and PE^t
        Make the environmental selection to conform the new extern population PE^(t+1)
        Apply the selection operator by binary tournament with replacement on PE^(t+1).
```

Apply the crossover and mutation operators on the selected population.
Asign the new population to P^{t+1}.
t ← t +1
End While
End

Fig. 2. Proposed Algorithm

5 Experimentation and Results

5.1 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 *GVND* stands for the cardinality of the Pareto front of the execution. 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, $P_{crossover\_pahts}$ was 0.4 and $P_{mutation}$ was 0.1.

5.2 Results

Table 1 shows the minimum, maximum, average values and standard deviation for the different flows on the 10-node destination set. 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 2 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.

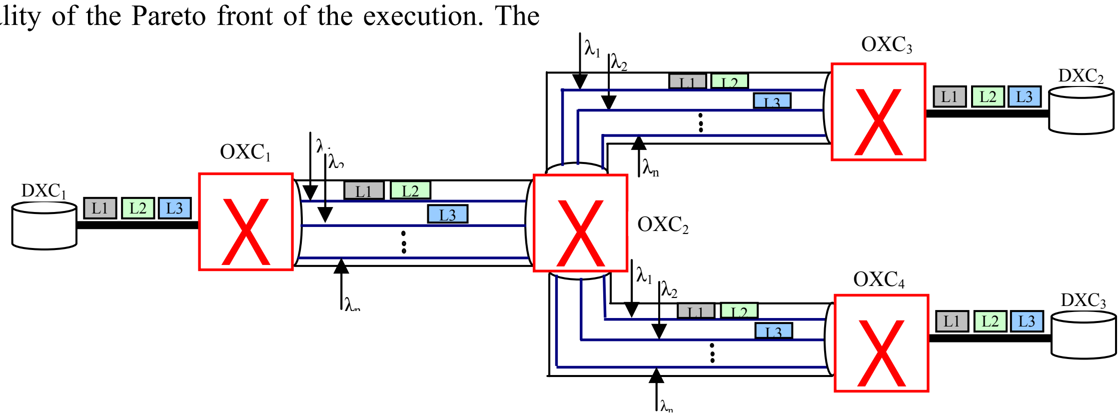

Fig 3. Number of wavelengths used on a multicast transmission.

	MIN			MAX			AVG			DEV		
	λs	AT	DL	λs	AT	DL	λs	AT	DL	λs	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 1. 10-node destination set results.

	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 2. Average Generational Distance

6 Conclusions

A multiobjective optimization model scheme that minimizes simultaneously three functions has been proposed on this paper. 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.

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