Multi-Objective Scheme over Multi-Tree Routing in Multicast MPLS Networks

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Abstract **–This paper proposes a traffic engineering scheme using different distribution trees to several multicast flows. We formulate this problem as one with Non Linear programming with discontinuous derivatives (DNLP). The aim is to combine into a single aggregated metric the following weighting objectives: the maximum link utilization, the hop count, the total bandwidth consumption and the total end-to-end delay. Our proposal solves the traffic split ratio for multiple trees. The proposed approach is applied in MPLS networks by allowing the establishment of explicit routes in multicast events. Furthermore, the results obtained with GAMS tools show that several objectives are decreased; the maximum link utilization is minimized. The main contribution of this paper is the optimization model and the formulation of the multi-objective function.**

Index terms - Networks, Optimization, Multipath Channels, Traffic Engineering

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I. INTRODUCTION

Traffic engineering is concerned with optimizing the performance of operational networks. The main objective is to reduce congestion hot spots and improve resource utilization. This can be achieved by setting up explicit routes over the physical network in such a way that the traffic distribution is balanced across several traffic trunks [1].

This load balancing technique can be achieved by a multicommodity network flow formulation that leads to the traffic being shared over multiple routes between the ingress node and the egress nodes. In the multipath approach, the data is transmitted over different paths to achieve the aggregated end-to-end bandwidth requirement. The advantages of using multipath routing are discussed in [2]. However, multiple trees may require more total network bandwidth resources (i.e. the sum of assigned bandwidth at each link of the trees) than the single shortest tree. Therefore, the maximum hop-count constraint needs to be incorporated into multitree routing schemes so as not to waste bandwidth. In addition, as the number of trees will be restricted between a particular source-destination pair in the real network topology, the maximum path-count constraint needs to be considered in multipath routing.

Multicast connections are connections between one or more senders and a number of members of a group. The aim of multicasting is to be able to send data from a sender to the members of a group in an efficient manner [3]. For multicast transmission, the traffic is split across multiple trees between the ingress node and the set of egress nodes. When we translate this into a mathematical formulation, the objective is to minimize the maximum link utilization.

Many multicast applications, such as audio and videoconferencing or collaborative environments and distributed interactive simulation, have multiple quality-of-service requirements on bandwidth, packet delay, packet loss, cost, etc. When the network is congested due to some flow transmissions having a rate higher than the shortest path capacity, the minimization of the maximum link utilization involves: 1) reducing the total packet delay, 2) minimizing the total packet loss, and 3) minimizing the congestion of links.

In this paper, we propose a generic multi-objective load-balancing scheme to create multiple trees based on weighting methods [4] which includes the maximum link utilization (α), the hop count (HC), the total bandwidth consumption (BC), and the total end-to-end delay (DL). The solution obtained from the model forms multiple trees for transporting several multicast flows. A generic multi-objective, optimization problem includes a set of m decision variables, a set of o objective functions and a set of z restrictions. The aim to multiobjective optimization is the concept of an efficient solution, where any improvement of one objective can only be achieved at the expense of another.

The load balancing problem in Multiprotocol Label Switching (MPLS) networks concerns the allocation of flow between two or more Label Switched Paths (LSPs) which share the same ingress and egress nodes. Multiple paths can be used to forward packets belonging to the same "forwarding equivalent class (FEC)" by explicit routing. With this load balancing technique, the load is split across multiple LSPs [5] depending on the solution obtained.

The split ratio is fed to the routers which divide the traffic of the same pair of ingress-egress nodes into multiple paths. Partitioning a traffic demand will be done by adjusting the output range of the hashing function [6].

The rest of this paper is organized as follows. In section II, we describe some related work. In section III, we define the formulation of the problem and the proposed generic multi-objective load-balancing optimization model. In section IV, we describe our proposal for an architecture formed by three planes upon which the MPLS trees are built. In section V, we present a performance analysis based on link utilization, by comparing the results obtained from the various optimization problems considered. Finally, we give some conclusions and describe related future work.

II. RELATED WORK

Various traffic engineering solutions using techniques to balance loads by multiple routes have been designed and analyzed in different studies. It should be pointed out that these proposals can be applied to MPLS networks. Table I summarizes the main characteristics of these proposals and our own optimization model which is presented in the following sections. In [7], Rao and Batsell consider two generic routing algorithms that plan

multipaths, consisting of possibly overlapping paths, wherein bandwidth can be reserved, and guaranteed, once reserved, on the links. The first problem deals with transmitting a message of finite length from ingress node to egress node within *r* units of time. A polynomial-time algorithm is proposed and the results of a simulation are used to illustrate its applicability. The second problem deals with transmitting a sequence of some units at such a rate that the maximum time difference between two units received out of order is limited. The authors show that this second problem is computationally intractable, and propose a polynomial-time approximation algorithm. Therefore, Quality of Service (QoS) routing via multiple paths under a time constraint is proposed when the bandwidth can be reserved

In [8], Chen and Chan propose an algorithm to carry out the unicast transmission of applications requiring minimum bandwidth through multiple routes. The algorithm consists of five steps: a) the multipath P set is initialized as empty; b) the maximum flow graph is obtained; c) the shortest route from the ingress node to the egress node is obtained; d) the bandwidth consumption obtained in the maximum flow of step b is decreased and e) step (d) is repeated until the required bandwidth for transmission is reached. The results they present show very similar end-to-end delay values to those obtained independently whether or not the load balancing is being applied. However, link utilization is improved when the load balancing is applied.

In [9], Wang *et al* present a multi-objective optimization scheme to transport unicast flows. In this scheme, the maximum link utilization (α) and the selection of best routes based on the flow allocation through each link is considered. Any long routes that do not contribute positively to improving performance are eliminated. The minimization of the total bandwidth consumption over all the links through objective function minimization is also proposed.

In [10] Lee *et al* propose a method for transporting unicast flows. The constraint of a maximum number of hops is added to the minimization of the maximum link utilization. Moreover, a division of the traffic over multiple routes in a discrete way is established. This division simplifies the implementation of the solution. The behaviors of five approaches are analyzed: Shortest path based on non-bifurcation, ECMP (Equal Cost Multiple Paths), Traffic bifurcation, H Hop-constrained traffic bifurcation and H Hop-constrained traffic bifurcation with node affinity. Through the approaches of Hop-constrained traffic bifurcation, a minimum value of the maximum link utilization (α) is obtained.

In [11], Seok *et al* propose Non-bifurcation and bifurcation methods to transport multicast flows with hop-count constrained. In the analysis of results and simulations, they consider the Non-bifurcation methods only. The constraint of consumption bandwidth is added to the constraints considered in [10]. In [11] a heuristic is proposed. The proposed algorithm consists of two parts: 1) modifying the original graph to the hop-count constrained version, 2) finding a multicast tree to minimize the maximum link utilization. The time complexity of the proposed algorithm is bounded by $O(n^3 logn+n^2)$, where n is the number of nodes. None of the above proposals consider how to find the appropriate multiple trees to minimize all four features - maximum link utilization, number of hops, end-to-end delay and total bandwidth consumption, which we address in our optimization model proposed in this paper.

TABLE I
Type of transported flow and constraints

	FLOW	OBJECTIVES	CONSTRAINTS						PATH/TREES
[7] Rao & Batsell	Unicast	Multi objective			DL	BC			Multi-Path
[8] Chen & Chan	Unicast	Multi objective				BC			Multi-Path
[9] Wang, Wang & Zhang	Unicast	Multi objective	MLU			BC	FA		One and Multiple Paths
[10] Lee, Seok, Choi & Kim	Unicast	One objective		HC					Multi-Path
[11] Seok, Lee, Choi & Kim	Multicast	Multi objective	MLU	HC		BC			Only One Tree
This paper	Multicast	Multi objective	MLU	HC	DL	BC		MSF	Multi-tree

MLU: maximum link utilization
HC: hop count
DL: total delay
BC: total bandwidth consumption
FA: flows allocation
MSF: maximum number of subflows. Handle of flow fraction by each egress node across a link in the optimization model.

III. PROBLEM FORMULATION

The network is modeled as a directed graph $G=(N,E)$, where N is the set of nodes and E is the set of links. Let $s \in N$ be the ingress node. Let $t \in T$ be any egress node, where T is the set of egress nodes. Let $(i,j) \in E$, be the link from node i to node j, and let c_{ij} be the capacity of this link.

Let bw_f be the traffic demand of flow f from the ingress node s to the egress nodes subset T_f, where $f \in F$ is any flow, F is the flow set and T_f is the egress nodes subset to the multicast flow f. $T = \bigcup_{f \in F} T_f$.

Let X_{ij}^{tf} be the fraction of flow f to destination node t assigned to link *(i,j)*. Note that these variables include the egress node (t), which is not considered in previous works. As a consequence, the bandwidth consumption with destination to the set of egress nodes is controlled in each link. Furthermore, it is possible to maintain exactly, the constraint of flow equilibrium to the intermediate nodes.

The integer variable Y_{ij}^{tf} decides whether link *(i,j)* is used (1) or not (0) for the multicast tree rooted at the ingress node s and reaching egress node subset T_f.

Let v_{ij} be the delay of link (i,j).

Let m be the number of terms in the multi-objective function.

Let N_T be the maximum number of bifurcation paths for each node.

The problem of minimizing n multicast flows from source node s to the egress nodes of each subset T_f is formulated as follows:

Minimize

$$r_1.\alpha + r_2 \sum_{f \in F} \sum_{t \in T_f} \sum_{(i,j) \in E} Y_{ij}^{tf} + r_3 \sum_{f \in F} \sum_{t(i,j) \in E} bw_f \max_{t \in T_f}\left(X_{ij}^{tf}\right) + r_4 \sum_{f \in F} \sum_{t \in T_f} \sum_{(i,j) \in E} v_{ij} Y_{ij}^{tf}$$

(MLU-HC-DL-BC model)

Subject to

$$\sum_{(i,j) \in E} X_{ij}^{tf} - \sum_{(j,i) \in E} X_{ji}^{tf} = 1 \quad , t \in T_f, f \in F, i = s \tag{1}$$

$$\sum_{(i,j) \in E} X_{ij}^{tf} - \sum_{(j,i) \in E} X_{ji}^{tf} = -1 \quad , i, t \in T_f, f \in F, i \in T_f \tag{2}$$

$$\sum_{(i,j)\in E} X_{ij}^{tf} - \sum_{(j,i)\in E} X_{ji}^{tf} = 0 \quad ,t \in T_f, f \in F, i \neq s, i \notin T_f \tag{3}$$

$$\sum_{f\in F} bw_f . \max_{t\in T_f}(X_{ij}^{tf}) \leq c_{ij}.\alpha \quad ,\alpha \geq 0,(i,j)\in E \tag{4}$$

$$\sum_{j\in N} Y_{ij}^{tf} \leq N_T \quad ,i \in N, t \in T_f, f \in F \tag{5}$$

where

$$X_{ij}^{tf} \in \Re, 0 \leq X_{ij}^{tf} \leq 1 \tag{6}$$

$$Y_{ij}^{tf} = \lceil X_{ij}^{tf} \rceil = \begin{cases} 0 & ,X_{ij}^{tf} = 0 \\ 1 & ,0 < X_{ij}^{tf} \leq 1 \end{cases} \tag{7}$$

$$\sum_{i=1}^{m} r_i = 1, \quad r_i \in \Re, \quad r_i \geq 0, m \geq 0 \tag{8}$$

The Multi-objective function (MLU-HC-BC-DL model) defines a function and generates a single aggregated metric for a combination of weighting objectives:

The main objective consists of minimizing the maximum link utilization (α). In this case, the solution obtained may report long routes.

In order to eliminate these routes and to minimize hop count (HC), the term $\sum_{f\in F}\sum_{t\in T_f}\sum_{(i,j)\in E} Y_{ij}^{tf}$ is added. This is needed because, the objective function may report only the most congested link and the optimal solution may include unnecessarily long paths in order to avoid the bottleneck link [1].

In order to minimize the total bandwidth consumption (BC) over all links, the term $\sum_{f\in F}\sum_{t(i,j)\in E} bw_f \max_{t\in T_f}\left(X_{ij}^{tf}\right)$ is also added. This is included so that, if there is more than one solution with the best maximum link utilization, the solution with the minimum resource utilization is chosen.

Furthermore, in order to minimize the total end-to-end delay (DL) over all links, the term $\sum_{f\in F}\sum_{t\in T_f}\sum_{(i,j)\in E} v_{ij}\, Y_{ij}^{tf}$ is also added.

Constraint (1) ensures that the total flow emerging from ingress node to any egress node *t* at flow *f* should be 1.

Constraint (2) ensures that the total flow coming from an egress node *t* at flow *f* should be 1.

Constraint (3) ensures that for any intermediate node different from the ingress node (i ≠ s) and egress nodes $(i \notin T)$, the sum of their output flows to the egress node *t* minus the input flows with destination egress node *t* at flow *f* should be 0.

Constraints (1), (2) and (3) are flow conservation constraints.

Constraint (4) is the maximum link utilization constraint. In an unicast connection, the total amount of bandwidth consumed by all the flows with destination to the egress node *t* must not exceed the maximum utilization (α) per link capacity c_{ij}, that is, $\sum_{f\in F} bw_f \sum_{t\in T} . X_{ij}^{tf} \leq c_{ij}.\alpha, (i,j)\in E$. Nevertheless, in a multicast connection only the maximum value of X_{ij}^{tf} for $t \in T_f$ must be considered because, though the link *(i,j)* is the same for flow *f* and to different egress nodes, just one packet will be sent due to multicast IP specification.

If we apply the proposed optimization scheme to the topology of Fig. 1, where s=N1 and T={ N5, N6}, we obtain the solution (X_{ij}^{tf}), shown in Figure 2, for a single flow *f*. Note that the total flow coming from an egress node *t* is 1.

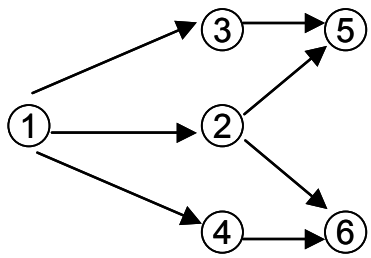

Fig. 1. Computer network topology.

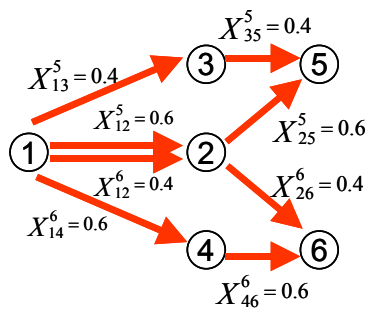

Fig 2. Optimum solution.

The simplest solution to link (1,2) is to send flows X_{12}^{5} and X_{12}^{6} to each member of the group separately (Fig. 3). When the same flow (4 and 5) is sent 2 times over this link, the network is inefficiently used. In this case, the maximum link utilization constraint is

$$\sum_{f \in F} \sum_{t \in T} bw_f . X_{ij}^{tf} \le c_{ij} . \alpha, (i, j) \in E .$$

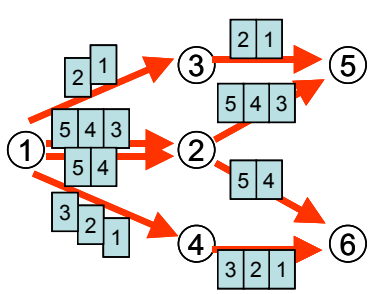

Fig 3. Unicast transmission.

When node 2 has multicast capabilities, it is not necessary to receive the two sub-flows. Only the maximum value of X_{12}^{5} and X_{12}^{6} is received. In this case, node 2 replicates the corresponding traffic flow by each output link and the maximum link utilization constraint is:

$$\sum_{f \in F} bw_f . \max_{t \in T_f} (X_{ij}^{tf}) \le c_{ij} . \alpha, (i, j) \in E .$$

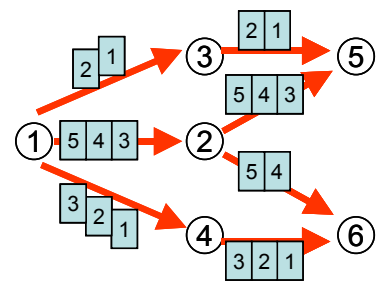

Fig 4. Multicast transmission.

The function *max* in constraint (4) generates discontinuous derivatives. For this reason, the problem should be solved through a GAMS tool for solving DNLP (Nonlinear programming with discontinuous derivatives) such as MINOS, MINOS5, COMOPT, COMOPT2, and SNOPT [12]. The DNLP problem is the same as the NLP (Nonlinear Programming) problem, except that non-smooth functions (abs, min, max) can appear.

Constraint (5) limits the maximum number of subflows through each node. Without this constraint, the model would suffer from scalability problems, i.e. the label space usage by LSPs would be too high.

Expression (6) shows that the X_{ij}^{tf} variables must be real numbers between 0 and 1. Solving the problem through X_{ij}^{tf} variables provides optimum flow values. These variables form multiple trees to

transport a multicast flow (see Section V). The demand between the ingress node and the egress node *t* may be split over multiple routes. When the problem is solved without load balancing, this variable will only be able to take values 0 and 1, which will show, respectively, whether or not the link *(i,j)* is used to carry information to the egress node *t*.

Expression (7) calculates Y_{ij}^{tf} as a function of X_{ij}^{tf} .

Finally, expression (8) shows that the weighting coefficients, r_i, assigned to objectives are normalized. These values are calculated through the solution of the optimization problem. As we will show in the experimental results, the MLU variable presents the highest priority.

Some particular optimization functions can be defined by setting one or more weighting coefficients (r_i) to zero (Table II).

TABLE II
Optimization functions

r_1	r_2	r_3	r_4	Model	Uni / Multi-Objective
- -	0	0	0	MLU	Uni
0	- -	0	0	HC	
0	0	- -	0	DL	
0	0	0	- -	BC	
- -	- -	0	0	MLU-HC	Multi
- -	0	- -	0	MLU-DL	
- -	0	0	- -	MLU-BC	
- -	- -	- -	0	MLU-HC-DL	
- -	- -	0	- -	MLU-HC-BC	
- -	0	- -	- -	MLU-DL-BC	
- -	- -	- -	- -	MLU-HC-DL-BC	

IV. ARCHITECTURE PROPOSED

Establishing these logical connections is possible by using MPLS technology, which is proposed as the support for multicast transmission in [13]. One way to establish routes in a MPLS network is by means of point-to-point (p-to-p) LSPs from the ingress node to the egress nodes. In conventional MPLS traffic engineering frameworks, only these p-to-p LSPs have been used. In this section, we present a three-level architecture for creating multiple trees with Label Switching Paths (LSPs) (see Fig. 1). In this architecture we propose to use point-to-multipoint (p-to-m) LSPs to create the tree between an ingress node and the set of egress nodes.

1. *LST Plane*. The optimization model provides a set of trees which will be named LST (Label Switch Tree) and which together form the LST Plane. A percentage of information flow is transported from the ingress node to the set of egress nodes through each one of these LSTs. In this plane, we consider disjoint LSTs.

2. *Point-to-multipoint LSP Plane*. Each one of the LSTs of the upper plane is a point-to-multipoint LSP (p-to-m LSP) which is established through explicit routes by any signaling protocol (RSVP, LDP, etc.). In this case, we propose using the RSVP-TE protocol adapted to multicast transmission [13]. On this plane, several p-to-m LSPs can be established over the same physical link.

3. *LSP Plane*. In this plane, only LSPs are considered. Therefore, it can only know that a part of the multicast flow is going from an ingress node to an egress node of the multicast group. In this plane, the Label Information Base (LIB) tables are created. These tables exchange the labels (logical value) to an output port (physical value).

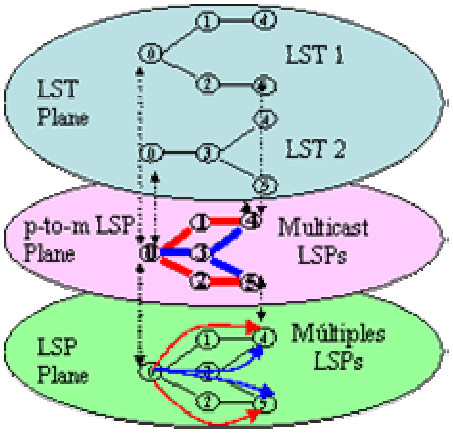

Fig 5. MPLS Architecture

V. EXPERIMENTAL RESULTS

a. Network topology

The optimization variables (α, HC, DL and BC values) are calculated using a GAMS solver called SNOPT. α is the maximum link utilization. HC is the hop count from ingress node to some egress node. DL is the end-to-end delay and BC is the bandwidth consumed.

The topology used is the 14-node NSF (National Science Foundation) network (Fig. 6). The costs on the links represent the delay and all links have 1.5 Mbps of bandwidth capacity. Two flows with the same source, s=N0, are transmitted for each analysis. The egress nodes subsets are T_1={N5, N8, N11} and T_2={N8, N11, N13}. We have considered that the transmission rates are 256 Kbps, 512 Kbps, 1 Mbps, 1.5 Mbps, 2 Mbps and 2.5 Mbps for each flow.

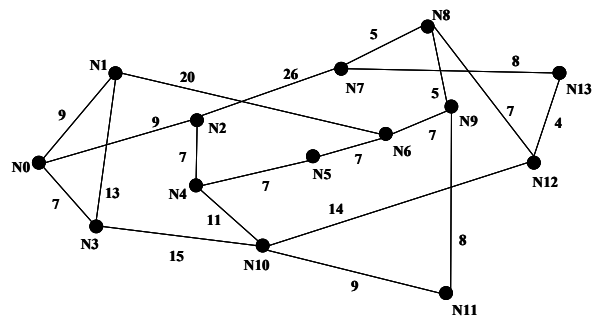

Fig 6. NSF network.

b. MLU-HC-DL-BC model solution example

Tables III and IV show the r_i and X_{ij}^{tf} values obtained using the MLU-HC-DL-BC model when flow rate is 512 Kbps. In this experiment, the maximum number of subflows by each node is not limited.

TABLE III
r_i values

r_1	r_2	r_3	r_4
0.997925	0.001	0.001	0.000075

TABLE IV

	f1					*f2*				
	t			X_{ij}^{t1}	$\max Y_{ij}^{t2}$	*t*			X_{ij}^{t2}	$\max Y_{ij}^{t1}$
link(i,j)	***5***	***8***	***11***			***8***	***11***	***13***		
(0,1)	X	X	X	0.72	1					
(0 ,2)	X	X	X	0.28	1	X	X	X	0.28	1
(0 ,3)						X	X	X	0.72	1
(1 ,6)	X	X	X	0.72	1					
(2 ,4)	X		X	0.28	1					
(2 ,7)		X		0.28	1	X	X	X	0.28	1
(3 ,10)						X	X	X	0.72	1
(4 ,5)	X			0.28	1					
(4 ,10)			X	0.28	1					
(6 ,5)	X			0.72	1					
(6 ,9)		X	X	0.72	1					
(7 ,8)		X		0.28	1	X	X		0.28	1
(7 ,13)								X	0.28	1
(8 ,9)							X		0.28	1
(9 ,8)		X		0.72	1					
(9 ,11)			X	0.72	1		X		0.28	1
(10,11)			X	0.28	1		X		0.72	1
(10,12)						X		X	0.72	1
(12,8)						X			0.72	1
(12,13)								X	0.72	1

X in column *t* represents that exist a flow in the link *(i,j)*, in which case the value is given by X_{ij}^{tf}

Fig. 7a. and 7b. show multiple trees to transport flows f1 and f2 respectively. In this case, the maximum number of subflows obtained are 2. Note in Fig. 6 that nodes N0 and N10 are topologically limited to 3 subflows, N5, N11 and N13 to 2 subflows and the other nodes are limited to 2.

The number of MPLS labels needed by each flow f (NL_f) is given by $\sum_{(i,j)\in E} \max_{t\in T_f}\left(Y_{ij}^{tf}\right)$. In this case, $NL_1 = 13$ and $NL_2 = 12$.

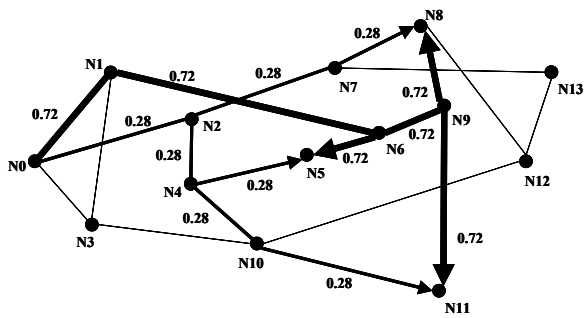

Fig. 7a. Trees to transport flow f1 of 512 Kbps (X_{ij}^{t1}).

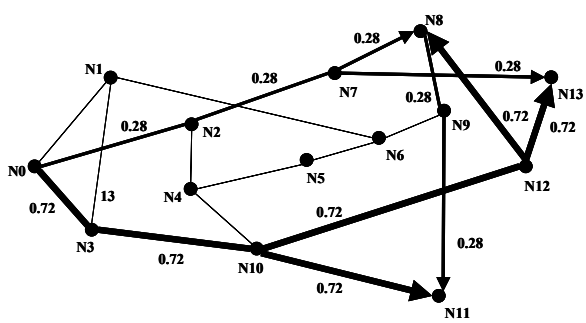

Fig. 7b. Trees to transport flow f2 of 512 Kbps (X_{ij}^{t2}).

c. Analysis of all models

Figures 8a, 8b, 8c and 8d show, respectively, the behavior of α (MLU), the percentage of total bandwidth consumed (BC), the number of hops (HC) and the end-to-end delay (DL) for all the models analyzed.

To find the minimum value of only one objective it is necessary to apply a particular function, that is to say, an MLU-model, an HC-model, a DL-model or a BC-model.

In general, the multi-objective MLU-HC-DL-BC model performs better than the other models, because several weighting objectives are reduced simultaneously.

In next figures (8a, 8b, 8c and 8d), the performance of MLU-HC-DL-BC model is highlighted in order to compare it more easily with the other models.

Fig. 8a shows that variable α is minimized by several models (MLU, MLU-HC-DL-BC, and others). Fig. 8b shows that BC obtained by MLU-HC-DL-BC is very near to minimum value obtained by the BC model. Fig. 8c and 8d show that HC and DL obtained by MLU-HC-DL-BC is near to minimum value obtained by the HC-model and the BC-model respectively.

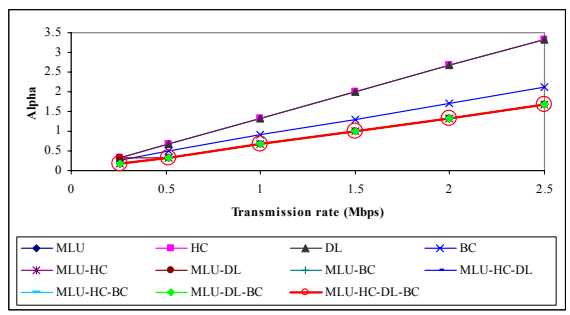

Fig. 8a. Comparisons of maximum link utilization (α) of all optimization models.

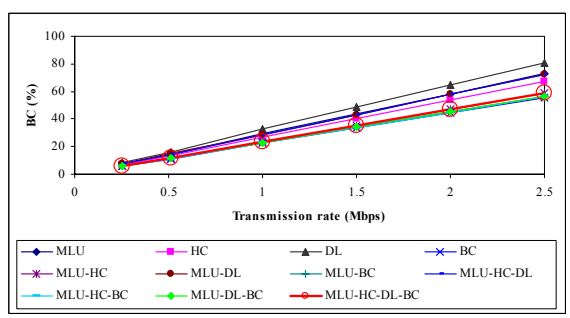

Fig. 8b. Comparisons of bandwidth consumption (BC) of all optimization models.

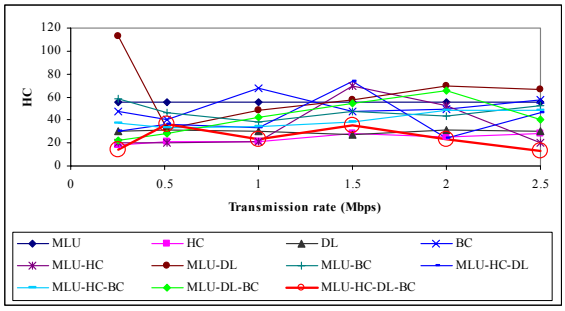

Fig. 8c. Comparisons of hop count (HC) of all optimization models.

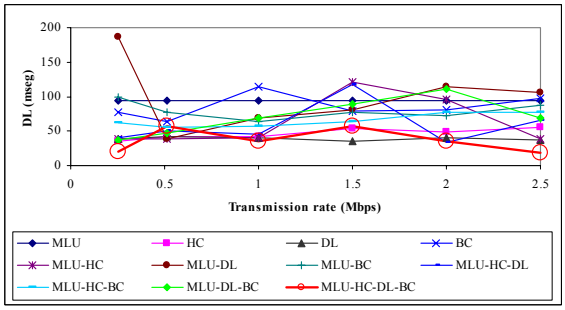

Fig. 8d. Comparisons of total end-to-end delay (DL) of all optimization models.

d. Normalized values

In order to compare the MLU-HC-DL-BC values obtained with the different optimization models, different normalized values were also calculated: i.e. $\hat{\alpha}_{Model_Y\ vs\ Model_X} = \frac{\alpha_{Model_Y} - \alpha_{Model_X}}{\alpha_{Model_X}}$ where *Model_Y* is the MLU-HC-DL-BC model and *Model_X* is another model. These calculations of normalized α have been made to compare the incidence of increments or decrements of one optimization model with respect to another.

Fig. 9a, 9b, 9c and 9d respectively, show the normalized value of the multi-objective model MLU-HC-DL-BC compared to the models for α (MLU), the percentage of total bandwidth consumed (BC), the number of hops (HC) and the end-to-end delay (DL).

In Fig. 9a it can be seen that in order to minimize α, the multi-objective model performs better than the HC and DL models, with a reduction of 50%. A reduction of 20 to 40 % is obtained with respect to the BC model, while the minimization values are exactly the same as they are for the MLU model.

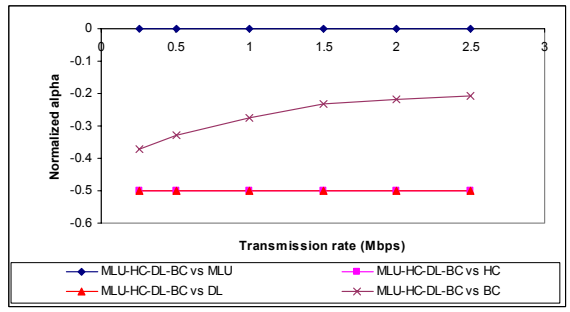

Fig. 9a. Normalized α.

Figure 9b shows that for minimization of BC, the multi-objective model performs better than the DL, MLU and HC models, with reductions of 28%, 20% and 14% respectively. Compared to the BC model, it has an increase of only 5%.

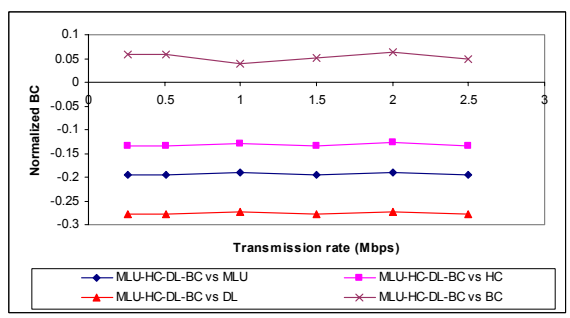

Fig. 9b. Normalized bandwidth consumption.

Figure 9c shows that for minimization of HC, the multi-objective model performs better than the MLU model (between 40% and 80% reductions) and BC model (between 10% and 80% reductions). Compared to the DL model, there was a reduction of between 20% and 60%, except for transmission rate values of 512 Kbps and 1.5 Mbps, where there was an increase

of between 10% and 20%. Compared to the HC model, there was a reduction of between 20% and 50% for very low (256 Kbps) and very high (2 to 2.5 Mbps) transmission rates. However, for the transmission rates in between these low and high values, there was an increase of about 20%, except at 512 Kbps where there was a peak increase of 70%.

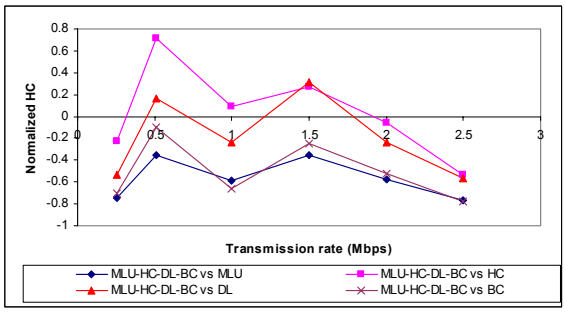

Fig. 9c. Normalized hops count.

Figure 9d shows that for minimization of DL, the multi-objective model performs better than the MLU model (between 40% and 80% reductions) and BC model (between 10% and 80% reductions). Compared to the HC model, there was a reduction of between 20% and 60%, except for transmission rate value of 512 Kbps, where there was an increase of 40%. Compared to the DL model, there was a reduction of 40% for very low (256 Kbps) and very high (2 to 2.5 Mbps) transmission rates. However, for the transmission rates in between these low and high values, there was an increase of between 40% and 60%%, except at 1024 Kbps where the value was the same as for the DL model.

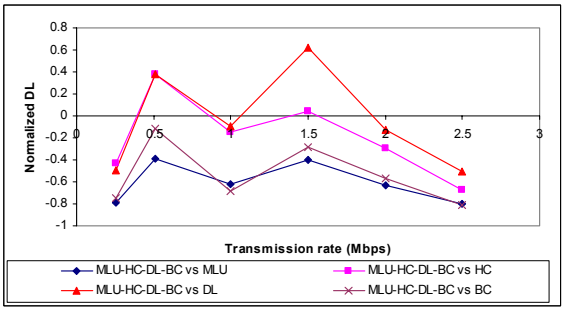

Fig. 9d. Normalized delay.

For the α and BC variables, the MLU-HC-DL-BC model performed as well as or better than the other models.

For the HC variable, the MLU-HC-DL-BC model performed as well as or better than the other models, except in those models where HC is the optimization variable, in which cases there was a maximum increase of 20%

For the DL variable, the MLU-HC-DL-BC model performed in general, as well as the HC model.

The most important conclusion is than P-MHDB model shows generally a better behavior than the other models for transmission rate higher to 1.5Mbps, that is, when the network begins to be in congestion due to link capacity and traffic demand.

e. Other results

We measure the running time of GAMS on a PC running MS Windows XP with Pentium 1.2 GHz a 256 Mb of RAM memory. The mean value was 320 msec. The maximum value was 390 msec. The minimum value was 290 msec. In the tests carried out, we did not observe significant increases in execution times when the MLU-HC-DL-BC model was considered.

FUTURE WORK

For further study, we will consider other topologies and flows; the hop count restriction will be added to this model and we will attempt to demonstrate that the trees created in this model form the shortest-path tree. Furthermore, with regard to the N_T value, we will analyze a model in terms of the link capacity and flow transmissions.

When a new multicast flow is to be transported, the proposed optimization scheme will be applied to a new topology where link capacity is updated with initial link capacity, subtracting the bandwidth consumption of previously considered flows.

Since the members of the multicast group cannot be assumed to be static, we will design an algorithm for dynamic traffic. In this case, an auxiliary optimization model will be formulated.

While in single-objective optimization the optimal solution is usually clearly defined, this does not hold for multiobjective optimization problems. Instead of a single optimum, there is a set of alternative trade-offs, generally known as Pareto-optimal solutions. These solutions are optimal in the wider sense that no other solutions in the search space are superior to them when all objectives are considered. Several optimization runs with different parameter settings are performed in order to achieve a set of solutions which approximates the Pareto-optimal set. Evolutionary Algorithms (EA) seem to be especially suited to multiobjective optimization because they are able to capture multiple Pareto-optimal solutions in a single run and may exploit similarities of solutions by recombination [14]. We will investigate the applicability of EA in the multi-objective load-balancing scheme proposed in this paper.

CONCLUSIONS

In this paper, we have presented multi-tree routing to develop a multicast transmission with load balancing, using multiple trees. We have employed a multi-objective, load-balancing scheme to minimize: the maximum link utilization (α), the hop count (HC), the total bandwidth consumption (BC), and the total end-to-end delay (DL). By introducing HC, lengthy paths are eliminated. By introducing BC, the bandwidth consumption by links is minimized.

The variables are X_{ij}^{tf}, which is the fraction of the bandwidth of demand (bw_f) with destination to the t node assigned to the (i,j) link, and the solution to the optimization problem. These variables split the traffic through the different trees.

In the results, we showed that the multi-objective model, MLU-HC-DL-BC, performed well at simultaneously minimizing the multiple objectives. We also showed that this multi-objective model came close to the minimum values obtained by all the models.

We proposed a three dimensional architecture - comprising an LST plane, a point-to-multipoint plane and an LSP plane - in order to achieve implementation of the multiple trees by means of technology such as MPLS.

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