# Threshold-Based Policy for LSP and Lightpath Setup in GMPLS Networks

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*Abstract*— **In this paper, a new policy is introduced to determine and adapt the Generalized MultiProtocol Label Switching (GMPLS) network topology based on the current traffic load. The objective of the new policy is to minimize the costs involving bandwidth, switching and signaling. The new policy is based on a threshold criterion. The policy is split into two levels, the first deals with the MPLS network and the second with the lightpath level. The two thresholds depend on the cost coefficients and the number of the intermediate hops. Our policy also performs a filtering control to avoid oscillations which occur due to highly variable traffic. The proposed policy has been evaluated by simulation and numerical results, which show its effectiveness and the achieved performance improvement.**

## I. INTRODUCTION

It is desired of a truly integrated multi-service IP network to provide differentiated Quality of Service (QoS) to different applications and users. Such IP networks are becoming more feasible with the current advancements such as *e.g.* Differentiated Services (DiffServ) architecture, MultiProtocol Label Switching (MPLS) etc., the underlying physical network components, *i.e.* optical networking technology, and their integration Generalized MPLS (GMPLS).

GMPLS is the proposed control plane solution for next generation optical networking. It is an extension to MPLS that enables Generalized Label Switched Paths (G-LSPs) such as light paths, to be automatically setup and torn down by means of a signaling protocol [1]. GMPLS differs from traditional MPLS because of its added switching capabilities for lambda, fiber etc. An all-optical path between edges of the network is called a lightpath and is created by reserving a dedicated wavelength channel on every link along the path. However optical networks do not use statistical sharing of resources, and therefore provide low bandwidth utilization. To overcome this problem, consider a network architecture where different MPLS networks (for different traffic classes) are built over the optical network and each lightpath is assigned to LSPs carrying traffic aggregates.

Many virtual topology design algorithms [2], [3] for wavelength routed optical networks have been proposed in literature. A survey of many more such algorithms is given in [4]. A scheme for optical network design with lightpath protection is given in [5]. A wavelength routing and assignment algorithm for optical networks with focus on maximizing the wavelength utilization at the switches is given in [6]. However, all these algorithms design the network off-line with a given traffic matrix for the network. In this paper, we propose an online dynamic algorithm for topology adaptation in optical networks that is based on bandwidth request events as they occur.

In our previous paper [7], we introduce a new decision policy that provides an on-line design for MPLS network depending on current traffic load. The motivation for the development of a combined method to control the topological structure of both the optical network and the MPLS networks is based on the concept of Integrated Traffic Engineering (ITE). ITE involves coordinated and collaborative forecasting, planning, performance optimization and replenishment of network capacity.

The contribution of this paper is a method to dynamically setup and tear-down not only LSPs but also lightpaths in response to new traffic demands originating between routers in order to operate the Internet backbone networks more efficiently. This will also allow to adjust the virtual topologies at MPLS level and lightpath network level. The method is based on comparison of the total traffic with a threshold. The threshold is derived from economic considerations related to bandwidth reservation/utilization, switching and signaling the new LSP/lightpath information in the network. The threshold calculation is very simple and requires knowledge of only few network-wide constant parameters along with local node state. Thus, our method is highly scalable and easy to implement.

This paper is organized as follows. In section 2, the hierarchical LSP setup problem is formulated and solved, and the policy structure is described. The policy is tested by simulation and numerical examples are shown in Section 3. Conclusions are given in Section 4.

## II. HIERARCHICAL LSP AND LIGHTPATH SETUP PROBLEM

In this formulation, we are handling the problem of LSP creation at three levels, namely the MPLS, lightpath and fiber levels. Since similar state variables will be used for each of the levels, we introduce the notation that the superscript

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This work was supported by NSF under award number 0219829 and NASA under contract number S11201 (NAS5-01090)

distinguishes between the different level variables. To be more specific, we define the following variables:

- $G^F(N, L^F)$ : (Physical) Topology of fiber network
- $G^\lambda(N, L^\lambda)$ : (Virtual) Topology of lightpath network
- $G^{LSP}(N, L^{LSP})$ : (Virtual) Topology of MPLS network

Here, $N$ is the set of nodes in the network and is common between the physical and virtual topologies. $L^F$ denotes the set of links in the fiber network. Thus, each $l_{ij}^F \in L^F$ is a fiber connection between the nodes $i$ and $j$ ($i, j \in N$). $L^\lambda$ and $L^{LSP}$ denote the virtual topology of the lightpath and MPLS networks, respectively. Each $l_{ij}^{\lambda i} \in L^\lambda$ is a lightpath between the nodes $i$ and $j$ (using wavelength $\lambda i$), and each $l_{ij}^{LSP} \in L^{LSP}$ is an LSP between the nodes $i$ and $j$. We assume that there are no wavelength converters in the network. Here, we introduce the concept of "default LSPs and lightpaths." The default lightpaths are mapped onto the fiber network *i.e.* each fiber in $L^F$ contains one default lightpath. We assume that whenever a lightpath exists between a node pair, a default LSP is also created for the same node pair. However, it is possible to have a direct LSP between the node pair which is not routed on a single default lightpath. We call it a non-default direct LSP. For each fiber/lightpath/LSP, we define:

- $C_{ij}^F, /C_{ij}^\lambda, /C_{ij}^{LSP}$ : Capacity of fiber, lightpath, LSP between nodes $i$ and $j$, respectively
- $A_{ij}^F, /A_{ij}^\lambda, /A_{ij}^{LSP}$ : Available capacity on fiber, lightpath, LSP between nodes $i$ and $j$, respectively

Also, $B_{ij}$ is the total bandwidth reserved between routers $i$ and $j$. We define the following path variables:

- $P_{ij}^F$ : Minimum hop path on the fiber network between nodes $i$ and $j$
- $P_{ij}^\lambda$ : Minimum hop path between nodes $i$ and $j$ on $L^\lambda$, the lightpath network
- $P_{ij}^{LSP}$: Concatenation of default LSPs overlaying $P_{ij}^\lambda$.

We assume that there is only one fiber between the nodes that are connected. We also assume that the minimum hop path $P_{ij}^F$ between any two nodes $i$ and $j$ stays constant during our analysis. We also assume that a suitable WDM technology is employed and it provides $M$ distinct wavelengths for simultaneous use on a fiber. The default LSPs are used to route MPLS traffic between two nodes when there is no direct LSP or not enough available bandwidth on the direct LSP. Thus, in an MPLS network, the bandwidth requests between $i$ and $j$ are routed either on a direct LSP $l_{ij}^{LSP}$ or on $P_{ij}^{LSP}$, a concatenation of default LSPs overlaying $P_{ij}^\lambda$.

When a new bandwidth request $b_{ij}$ arrives between routers $i$ and $j$ in the MPLS network, the existence of a direct LSP between $i$ and $j$ is checked initially. For direct LSP between $i$ and $j$, the available capacity $A_{ij}^{LSP}$ is compared with $b_{ij}$. If $A_{ij}^{LSP} > b_{ij}$, then the requested bandwidth is allocated on that LSP and the available capacity is reduced accordingly. Otherwise, $C_{ij}^{LSP}$ can be increased in order to satisfy the bandwidth request. If there exists no direct LSP between $i$ and $j$, then we need to decide whether to setup a new LSP and its according $C_{ij}^{LSP}$. Each time a new LSP is setup, the previously granted bandwidth allocation requests between $i$ and $j$ are re-routed on the new LSP. If we are not able to satisfy the request on the direct LSP, the request will be routed on $P_{ij}^{LSP}$, if there is enough available capacity on each default LSP in $P_{ij}^{LSP}$. If any of the default LSPs does not have the required available bandwidth, we redimension them. For this redimensioning, we borrow capacity from the available bandwidth in the corresponding lightpath, $A_{hk}^\lambda$. We identify the set $Q_{ij}^\lambda$ of lightpaths in $P_{ij}^\lambda$ where $A_{hk}^\lambda$ is less than $b_{ij}$, and decide whether to setup a new direct lightpath between $i$ and $j$. If the direct lightpath is not created, we add new capacity to the lightpaths in $Q_{ij}^\lambda$.

At the time of the departure of a bandwidth request, we check if the LSP where the request was routed is a candidate for being torn down. If the request was routed on a non-default direct LSP $l_{ij}^{LSP}$, we decide whether to teardown the LSP. However, if the request is routed on a default direct LSP $l_{ij}^{LSP}$, we have to consider the option of tearing down the LSP as well as the lightpath. The default LSPs and default lightpaths overlaying the fiber links in $L^F$ are never torn down.

### A. Formulation

The following definitions are provided for a node pair $i$, $j$. We assume that the definitions can be extended to other node pairs independently because the events for each node pair are assumed to be independent and we assume a centralized network manager that maintains the global network state. Thus, we will drop the subscript henceforth.

We denote bandwidth requests by $b$. A request specifies the amount of bandwidth requested and the origin and destination end-points of the request. We define the following events $e$:

- $e = 0$: Arrival of a bandwidth request $b$
- $e = 1$: Departure of $b$ routed on default direct LSP
- $e = 2$: Departure of $b$ from non-default direct LSP
- $e = 3$: Departure of $b$ from $P^{LSP}$

The MPLS state vector $s^{MPLS}$ for a node pair in the MPLS network is defined as $s^{MPLS} = [C^{LSP}, A^{LSP}, B^L, B^P]$. Here, $B^L$ is the part of $B$ that is routed on the direct LSP $l^{LSP}$ and $B^P$ is the part that is routed on $P^{LSP}$, the concatenation of the default LSPs. For a default LSP, $C^{LSP} > A^{LSP} + B^L$.

The state of a lightpath should include the available bandwidth on the lightpath and the value of the wavelength $\lambda$ used in the lightpath. We assume that all lightpaths are established with a capacity of $W$ and they are routed on $P^F$, the minimum hop path between the nodes on the fiber network . However, there may exist multiple lightpaths between the node pair. Thus, the lightpath state vector $s^\lambda$ for a node pair in the lightpath network is $s^\lambda = [B^\lambda,\ B^F, \Lambda, A^\Lambda]$ where $B^\lambda$ is the part of $B$ that is routed on the direct lightpaths between the node pair, $B^F$ is the part of $B$ that is routed on the lightpaths in $P^\lambda$, $\Lambda$ is the set of the wavelengths being used for the lightpaths between the node pair, and $A^\Lambda$ is the total available bandwidth on all the lightpaths between the node pair.

The fiber state vector $s^F$ at a given time instant for a node pair in the fiber network is $s^F = [\Omega]$ where $\Omega$ denotes the set of wavelengths still available on the fiber and not being used by some lightpath. Thus, $A^F = \#(\Omega) * W$ where $W$ is the capacity assigned to each wavelength by WDM.

We denote the full state for a node pair as $S = \langle S^{MPLS}, S^\lambda, S^F \rangle$ and the set of all possible network states as $\bar{S}$. Here, $S^\lambda$ is a tuple of the states $s^\lambda$ of the lightpaths in $P^\lambda$ and $S^F$ is a tuple of the states of the fibers in $P^F$. Note that the system state is unchanged unless an event occurs. The occurrence of an event triggers our decision policy which provides a suitable action to handle the event. Execution of the action changes the network state.

Assume that at time instant $t$, event $e$ occurs. The decision of setting up/tearing down or redimensioning the corresponding LSP is captured by the binary action variable $a^{MPLS}$, with $a^{MPLS} = 1$ meaning that the LSP will be setup/torndown or redimensioned and with $a^{MPLS} = 0$ meaning that no action will be taken and the incoming request is routed either on a existing direct LSP or on $P^{LSP}$. On the lightpath level, the decision is captured by the binary action variable $a^\lambda$, with $a^\lambda = 1$ meaning that the lightpath will be setup/torndown and with $a^\lambda = 0$ meaning that no action will be taken. We denote the combined actions at the two levels by $a$, i.e., $a = \langle a^{MPLS}, a^\lambda \rangle$.

A decision rule $d_i$ provides an action selection for each state at a given decision instant $t_i$. A decision policy $\pi$ specifies the decision rules to be used in the complete time horizon where the problem is considered, i.e., $\pi = \{d_0(\bar{S}), d_1(\bar{S}), d_2(\bar{S}), \ldots\}$.

We define an incremental cost function $W(S, a)$ associated with the system when a bandwidth request $b$ arrives and the actions $a^{MPLS}$ and $a^\lambda$ are taken. This cost is split into two levels. The first level corresponds to the MPLS network and the second level corresponds to the lightpath network. The cost at each level is the sum of three components: the bandwidth cost $W_b(S, a)$, the switching cost $W_{sw}(S, a)$, and the signaling cost $W_{sign}(S, a)$.

We assume that the rate at which MPLS bandwidth cost $W_b^{MPLS}(S, a)$ is incurred depends linearly on the bandwidth required and the number of hops $h^\lambda$ in the shortest path $P^\lambda$ on the lightpath network.

$$W_b^{MPLS}(S, a) = c_b \; h^\lambda \; B \; T, \tag{1}$$

where $c_b$ is the bandwidth cost coefficient per capacity unit (c.u.) for the MPLS network and the cost is incurred for the total traffic $B$ between the node pair. Here, $T$ is the time duration for which the bandwidth request is valid. The switching cost depends linearly on the number of switching operations in the MPLS network and the switched bandwidth. The additional switching cost incurred is given as:

$$\begin{aligned} W_{sw}^{MPLS}(S, 1) &= X(B^L + B^P + b)T \\ W_{sw}^{MPLS}(S, 0) &= \{XB^L + h^\lambda \; c_{ip}(B^P + b)\}T \\ & \quad \text{where } X = [c_{ip} + c_{mpls}(h^\lambda - 1)] \end{aligned} \tag{2}$$

where $c_{ip}$ and $c_{mpls}$ are the switching cost coefficients per c.u. in IP and MPLS mode respectively. The signaling cost is the cost incurred when a new LSP is setup or redimensioned. In our assumptions, redimensioning implies the same signaling cost as setting up a new LSP.

$$W_{sign}^{MPLS}(S, a) = a^{MPLS}[c_s \; h^\lambda + c_a], \tag{3}$$

where $c_s$ is the signaling cost coefficient per hop and $c_a$ is the fixed notification cost coefficient. This cost is not incurred if $a = 0$.

Next, we explain the cost components at the lightpath network level. The bandwidth cost $W_b^\lambda(S, a)$ incurred depends linearly on the number of hops $h^F$ in $P^F$ and the capacity of the lightpath.

$$W_b^\lambda(S, a) = c_{cap} W \; h^F \; T, \tag{4}$$

where $c_{cap}$ is the bandwidth cost coefficient per capacity unit (c.u.) for the lightpath network. The switching cost in the lightpath network depends on the number of switching operations in the optical and opto-electronic switches. The switching cost is given as

$$\begin{aligned} W_{sw}^\lambda(S, 1) &= Y(B^\lambda + B^F + b)T \\ W_{sw}^\lambda(S, 0) &= \{YB^\lambda + c_\lambda h^F \; (B^F + b)\}T \\ & \quad \text{where } Y = [(h^F - 1)c_{opt} + c_\lambda] \end{aligned} \tag{5}$$

where $c_{opt}$ is the cost coefficient for the switching of the lightpath in the optical switches on the path and $c_\lambda$ is the cost coefficient for the opto-electronic switching at the head-end of the lightpath. The signaling cost of a lightpath is made up of many components. As for the MPLS network, the signaling cost is incurred only when a new lightpath is being created or an old one being destroyed. The components of the signaling cost include $c_{sign}$ (the cost for signaling the information to all the relevant nodes) and $c_{comp}$ (the cost for the recomputation of the shortest paths between node pairs in the lightpath network after the modified topology; this modifies the paths $P^\lambda$ over which new LSPs can be routed), among others. These two components are fixed in nature and do not depend on the network topology. The other two components of the signaling cost are proportional to $h^F$, the number of hops on the physical path between the nodes. They are $c_{find\lambda}$ (the cost for finding the common wavelength to be used on the fibers in $P^F$) and $c_{allocate}$ (the cost of allocating that wavelength to the lightpath). The last component $c_{moving}$ relates to the cost of moving the existing traffic from one lightpath to another. After grouping the terms not dependent on $h^F$, the total signaling cost is

$$W_{sign}^\lambda(S, a) = a^\lambda[c_x + c_y h^F] \tag{6}$$

### B. Threshold-Based Setup Policy

A decision policy $\pi$ provides a sequence of decision rules at each decision instant in the considered time horizon. Here, we propose a greedy decision policy that minimizes the cost incurred at each decision instant. From the definition of the costs, the total cost is cumulative at each decision instant. Denoting the initial system state by $S_0$, we can write:

$$W(S_0, \pi) = \sum_m W(S_m, a_m), \tag{7}$$

where the subscripts are introduced to denote the successive states and actions. In our decision policy the action $a_m$ taken at instant $m$ depends only on the current state and not on the time of the decision. Our decision for each state is based on the following greedy criterion:

$$\alpha_m : W(S_m, \alpha_m) = \min_{a_m} W(S_m, a_m). \tag{8}$$

Thus, our decision policy is given as $\pi = \{d, d, \ldots\}$ since it is stationary and the individual decision rules provide the decision for the network states. The total cost with this policy becomes $W(S_0, \pi) = \sum_m W(S_m, a_m)$. The policy chooses actions in a state such that the instantaneous cost incurred is minimized. This leads to a threshold structure for our policy, *i.e.*, the decisions are based whether a threshold is exceeded or not. The action variables are given as:

$$a^{MPLS} = \begin{cases} 1 & B_{ij}^{P} + b_{ij} > B_{Th}^{MPLS} \\ 0 & \text{otherwise} \end{cases} \tag{9}$$

$$a^{\lambda} = \begin{cases} 1 & B_{ij}^{P} + B_{ij}^{L} + b_{ij} + B_{ij}^{pred} > B_{Th}^{\lambda} \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

Here $B_{Th}^{MPLS}$ denotes the threshold for setup/redimension of $l_{ij}^{LSP}$. It helps to choose the more economic option among the two options of setup/redimensioning the LSP or routing the request along $P^{LSP}$ (the multi-LSP path). The threshold can be calculated by comparing the costs for the two options as

$$B_{Th}^{MPLS} = \frac{c_s h^{\lambda} + c_a}{T(h^{\lambda} - 1)(c_{ip} - c_{mpls})}. \tag{11}$$

The threshold in Equation 10 helps to decide whether to create a new direct lightpath between the node pair. Our policy employs past statistics of the traffic between the node pair to predict the utilization of the lightpath. This is done to verify the economic viability of the creation of the lightpath. The threshold can be calculated by a similar cost comparison as before and it is given as

$$B_{Th}^{\lambda} = \frac{(h^F - \sum_{i \in \beta} h_i^F)(c_{cap} WT + c_y) - c_x(\beta - 1)}{T\left[(h^{\lambda} - 1)(c_{\lambda} - c_{opt}) + c_{cap} \sum_{i \in \eta} h_i^F\right]}. \tag{12}$$

Here, $\beta$ is the total number of lightpaths in $P^{\lambda}$ that do not have enough available bandwidth to satisfy the request and $\eta$ is the number of lightpaths that do not need modification. $h_i^F$ denotes the number of fibers corresponding to the lightpath $i$ among the $\beta$ lightpaths to be redimensioned. We used the relations $\beta + \eta = h^{\lambda}$ and $\sum_{i \in \beta, \eta} h_i^F = h^F$ to derive Equation (12). The complete algorithm for our LSP and lightpath setup policy for a single node pair is given in Figure 1.

## III. NUMERICAL RESULTS AND DISCUSSIONS

In our model, the cost functions are assumed to be linear with respect to the bandwidth requirements of the requests. There are two separate thresholds (Equations 11 and 12), the former for the MPLS layer and the latter for the optical layer. The MPLS threshold is only based on the number of hops in the path between the nodes in the MPLS network. Thus, as the distance between the nodes increases in the MPLS network, the threshold for creation/redimensioning of the corresponding LSP reduces. Similar observation can be made for the optical layer threshold. For increasing $\beta$ (number of lightpaths that need redimensioning), the threshold value reduces. This means that if a large number of lightpaths in $P^{\lambda}$ need redimensioning, our policy prefers to establish a direct lightpath.

Let us consider the scenario of a network where all the lightpaths correspond to a single fiber. Thus, $h^{\lambda} = h^F = h$ and $h_i^F = 1$. If $\beta = 1$, only one lightpath needs redimensioning. It is easy to see that the threshold in this case is smaller than if $\beta = 2$. Similar results can be obtained for the case when each lightpath corresponds to two fibers, i.e., $h^F = 2h,\ h^{\lambda} = h,\ h_i^F = 2$. Let us consider a case when all the lightpaths need to be redimensioned, i.e., $\beta = h^{\lambda}$, the threshold for creation of a direct lightpath becomes $-c_x/(c_{\lambda} - c_{opt})$. As this value is less than zero, it implies that the direct lightpath will be created even for a very small bandwidth request.

For the numerical examples, we use the network topology shown in Figure 2(a) and assign a capacity of 10Gbps to each lightpath. For this network, we start the simulation such that the three topologies $G^F$, $G^{\lambda}$ and $G^{LSP}$ coincide. In the Figure 2(a), we identify the links and the nodes for all the three topologies. Homogeneously increasing traffic loads are offered to the node pairs 1-7, 1-8, 1-9, 1-10, 2-7, 2-8, 2-9, and 2-10. In Figure 2, we show the evolution of the MPLS network for increasing traffic. We see that for an average traffic of 375 Mbps, the longest LSP between nodes 2-8 gets established, followed by LSPs 1-8, 1-9 and 2-7 for average traffic of 416 Mbps. Next, the LSPs 1-7, 1-10 and 2-9 are formed for traffic load of 500 Mbps. Last to be formed is the shortest LSP between nodes 2-10 for traffic of 750 Mbps. This evolution profile confirms the observation that the longer LSPs tend to be established first. When we increase the average traffic load even more, we start to see the evolution of the lightpath network topology (Figure 3). This gradual establishment of lightpaths illustrates the two observations made before. The first states that for a given $h^{\lambda}$, the threshold decreases with increasing $\beta$. This means that for a given path length, our policy tends to create a direct lightpath if more number of individual segments need redimensioning. The second observation states that for a given $\beta$, the threshold increases with increasing $h^{\lambda}$. This observation is complementary to the previous, since it implies that for a given number of individual segments to be redimensioned, longer lightpaths are more reluctant toward mutation. Thus, we see that for intermediate traffic loads, our policy created direct lightpaths selectively, instead of having a fully meshed topology from the beginning. In this way, we are adapting to the traffic in real-time in a highly economic manner. Also, it is important to observe from the two figures that the evolution sequence of the LSPs differs from the sequence for the lightpaths.

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LSP & Lightpath Setup/Redimensioning Policy
At time $t$, $S_{ij} = \langle[C_{ij}^{LSP}, A_{ij}^{LSP}, B_{ij}^{L}, B_{ij}^{P}], S_{ij}^{\lambda}, S_{ij}^{F}\rangle$ and event $e$ occurs
Case 0: $e =$ Arrival of $b_{ij}$
        If direct $l_{ij}^{LSP}$ exists with enough available bandwidth
            Request is accepted and routed on $l_{ij}^{LSP}$
        Else
            If all LSPs $\in P_{ij}^{LSP}$ have enough available capacity
                LSP Check: If total traffic between $i$ and $j$ exceeds $B_{Th}^{MPLS}$
                    If direct $l_{ij}^{LSP}$ exists $l_{ij}^{LSP}$ is redimensioned and request is accepted and routed on $l_{ij}^{LSP}$
                    Else new $l_{ij}^{LSP}$ is created and request is accepted and routed on $l_{ij}^{LSP}$
                Else request is accepted and routed on $P_{ij}^{LSP}$
            Else
                Identify all default $l_{hk}^{LSP} \in P_{ij}^{LSP}$ without enough available capacity. Let $\alpha$ be the number of such LSPs
                For each such $l_{hk}^{LSP}$
                    If the corresponding lightpath has enough available capacity $l_{hk}^{LSP}$ is redimensioned
                    Else identify lightpath $l_{hk}^{\lambda}$
                Let $\beta$ be the total number of lightpaths without enough available capacity
                Let $\eta$ be the number of lightpaths with enough available capacity ,i.e., $\beta + \eta = h^{\lambda}$
                If total traffic on $l_{ij}^{LSP}$ exceeds $B_{Th}^{\lambda}$
                    New direct $l_{ij}^{\lambda}$ and default $l_{ij}^{LSP}$ are created. Request accepted and routed on $l_{ij}^{LSP}$
                    Topologies $P_{ij}^{\lambda}$ and $P_{ij}^{LSP}$ are modified
                Else create $\beta$ new lightpaths $l_{hk}^{\lambda}$. $\beta$ default $l_{hk}^{LSP}$ are redimensioned. Jump to LSP Check
Case 1: $e =$ Departure of $b$ from default direct LSP
        If $B^{L} = b$ and $B^{P} = 0$ and $l_{ij}^{F}$ not exists, $l_{ij}^{LSP}$ and $l_{ij}^{\lambda}$ are torn-down
Case 2: $e =$ Departure of $b$ from non-default direct LSP
        If $B^{L} = b$ and $B^{P} = 0$ and $l_{ij}^{F}$ not exists, $l_{ij}^{LSP}$ is torn-down
Case 3: $e =$ Departure of $b$ from $P^{LSP}$
        Adjust $B^{P}$ accordingly
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Fig. 1. Threshold-Based Setup/Redimensioning Policy.

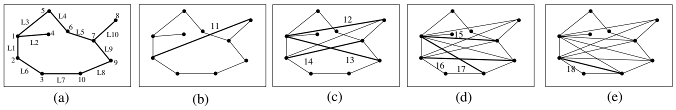

Fig. 2. Evolution of LSPs.

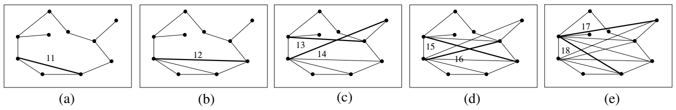

Fig. 3. Evolution of Lightpaths.

## IV. CONCLUSIONS

In this paper, we present a decision policy that provides the on-line design of a GMPLS network topology for the current traffic load. Adding/Deleting a direct LSP requires high signaling effort, but improves the switching of packets between the two routers. The decision at the MPLS level might lead to lightpath creation/deletion at the lightpath network level. Again, adding a new direct lightpath between a node pair requires a high signaling effort, but improves the switching of packets between the two hops.

The proposed policy is based on the network load, via a threshold which takes into account the bandwidth, switching and signaling costs. The proposed method was tested by simulation. The results confirm that the proposed policy is effective and improves network performance by reducing the cost incurred.

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