A Hierarchical Routing Approach for GMPLS-based Control Plane for ASON

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***Abstract*. A hierarchical network architecture is one of the hard recommendations stated at the Automatically Switched Optical Networks (ASON) specifications. This paper focuses on providing *ASON* with a hierarchical routing in order to ensure the scalability for large worldwide networks, mainly focusing on the functionality expected from GMPLS routing, such as aggregation schemes and routing algorithms, targeting to optimize the global network performance while guaranteeing scalability. Simulation results indeed show the benefits obtained owing to harder overhead reduction without impacting on the blocking probability.**

Keywords: OTN, ASON. Aggregation schemes, Hierarchical routing algorithms

I. INTRODUCTION

Optical Transport Networks (OTN) appear as a solution to support the new network requirements owing to broader network expectations produced by both an unimaginable increment of network users and the new emerging Internet applications. When this OTN incorporates automatic switching capabilities is named *ASON*, (Automatically Switched Optical Networks). A hierarchical network architecture comes out as one of the hard recommendations stated at the *ASON* specifications [1] to guarantee network scalability. Therefore, traditional flat network structures must be properly modified to fulfill that ASON recommendation. Main concepts to be modified are those related to signaling and routing, such as the network information aggregation, the network information dissemination, the updating policies and the routing algorithm, which all are covered by the *ASON* Control Plane.

It seems clear that such a *Control Plane* would be based on the Generalized Multi-Protocol Label Switching, *GMPLS* [2]. Document [3] focuses on the routing requirements for the GMPLS suite of protocols to support the capabilities and functionality of ASON control planes.

The following functionality is expected from GMPLS routing to instantiate ASON routing realization (see [4] and [5]):

- Support multiple hierarchical levels of Routing areas (RAs); the number of hierarchical levels to be supported is routing protocol implementation specific.
- Support hierarchical routing information dissemination including summarized routing information.
- Support for multiple links between nodes (and between RAs) and for link and node diversity.
- Support architectural evolution in terms of the number of levels of hierarchies, aggregation and segmentation of RAs.
- Support routing information based on a common set of information elements as defined in [4] and [5], divided between attributes pertaining to links and abstract nodes (each representing either a sub-network or simply a node).

The main advantage of hierarchical routing is to reduce large communication overhead while providing efficient routing. The routing algorithm dynamically computes paths supporting the QoS constraints required by the incoming call. Assuming source-based routing as the most commonly used QoS routing algorithms, routes are computed on the source nodes according to the routing information contained in their network state databases (named Traffic Engineering Database, *TED* when including QoS parameters).

The goal of this paper is to provide *ASON* with a hierarchical routing in order to ensure the scalability for large worldwide networks, mainly focusing on the functionality expected from GMPLS routing.

The remainder of this paper is organized as follows. Section II outlines main hierarchical network issues. In Section III we propose new approaches for both aggregating information and routing paths. Section IV evaluates the proposed mechanism and finally Section V concludes the paper.

II. HANDLING A HIERARCHICAL NETWOK STRUCTURE

A whole hierarchical network structure should be subdivided into routing areas (*RAs*), (see Fig.1 as an example) containing physical nodes with similar features. The *RA* nodes should exchange topology and resource information among themselves in order to maintain an identical view of the *RA*. This information should be contained in a Routing Controller (*RC*) component, which will respond both to requests from connection controllers (*CC*) for path information needed to set up connections and to requests for topology information from hierarchical mechanisms.

Each *RA* should be represented by a "*Logical Routing Area* (*LRA*) *Node*" in the next hierarchical level. The necessary functions to perform this role should be executed by a node

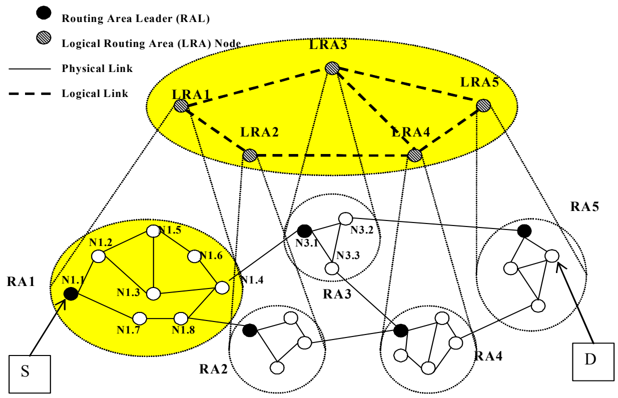

Fig.1 Hierarchical Network Structure

called the "*Routing Area Leader*" (*RAL*). This node will receive complete topology state information from all *RA* nodes and will send information up to the *LRA* node. The propagated information should only include the information needed by the higher level.

Once a hierarchical network structure has been described, we shortly review the ongoing work on the main hierarchical issues, i.e., the aggregation process, the dissemination process, the update policy and the hierarchical routing algorithm.

A. Network Information Aggregation.

There are many possible aggregation schemes. In [6] authors present a complete review of some of them as well as a new aggregation scheme named *Node Aggregation Scheme* (*NAS*) fully devoted to *ASON*. This scheme works as follows: 1) Compute all the lightpaths from node *i* to all border nodes, 2) Select the minimum number of wavelength per color that is available on each path and 3) Select the maximum value among the values computed in the step 2.

Even though simulation results presented in [6] show a significant reduction in the number of entries of the *Aggregated TED (ATED)* when the *NAS* is applied, unfortunately *NAS* utilization also drives to a non-negligible blocking probability increment, which can be over 3.5% when network load tops. Hence new approaches must be defined to reduce the aggregation impact on the blocking probability.

B. Network Information Dissemination

Routing information can be exchanged between adjacent levels of the routing hierarchy i.e. Level N+1 and N, where Level N represents the RAs contained by Level N+1. The links connecting RAs may be viewed as external links, and the links representing connectivity within an RA may be viewed as internal links. Therefore, according to Fig.1 an *RAL* sends information up to the *LRA* node. This information summarizes the topology/resource information received by the *RAL* from all the nodes belonging to the same *RA*. The communication between adjacent Routing Levels, that is, definition of type of information exchanged and interaction between upward and downward communication, is outside the scope of this paper.

C. Update Policy.

Update policies are required to guarantee that *ATED* content perfectly represents the current network state to guarantee an optimal path selection. In general update messages may be triggered by either a periodical refresh or a network change. While the former does not take into account the network dynamics the latter can drive to a significant signaling overhead in highly dynamic large networks despite low inaccuracy is guaranteed. Thus, new update policies must be developed to reduce this signaling overhead. This is achieved by reducing the number of update messages flooded throughout the network. The solution proposed in [7], suggests triggering an update message when a fixed number *N* (threshold value) of wavelengths changes their status, i.e. after a fixed number of *N* connections are established or released. This update policy is properly modified to be applied to hierarchical routing. Assuming that the update messages sent by the *RAL* nodes consist of aggregated information, i.e., information already reduced, the signaling overhead pending to be reduced is that produced into each *RA*. Hence, in hierarchical routing we only apply the update policy into each *RA*. Unfortunately this overhead reduction involves a blocking probability increment since the information used to select paths is not perfectly accurate. It has been demonstrated [8] that selecting paths under inaccurate network state information leads to have a significant connection blocking increment, known as the routing inaccuracy problem. In addition it is worth noting that the process of aggregating network state information also introduces a certain degree of inaccuracy in the *ATED* content on each network node. Therefore, the unavoidable and significant degree of introduced inaccuracy must be definitely taken into account when selecting paths, so defining the routing inaccuracy problem as a major problem in hierarchical networks.

D. Hierarchical Routing Algorithm.

Although *ASON* recommendations do not explicitly specify a routing algorithm they define a set of features that have to be supported by any routing algorithm running on an *OTN*. Source routing is one of these recommendations. Moreover as stated above hierarchical routing algorithms should include the routing inaccuracy problem as a key factor when selecting lightpaths.

There are not many significant contributions in the recent literature coping with the routing inaccuracy problem in hierarchical networks [6]. We present a new routing algorithm named *ALG3_H*, addressing the routing inaccuracy problem in OTN. *ALG3_H* is based on extending the routing algorithm ALG3, inferred from the *BYPASS Based Optical Routing* (*BBOR*) [7] mechanism, to be applied to hierarchical networks. The *BBOR* mechanism addresses the routing inaccuracy problem by providing the primary path with a set of pre-computed *bypass-paths* for all those intermediate nodes that would reject the set-up message, since the wavelength selected on the source node (primary path) might not be available during the set-up process, owing to the routing inaccuracy problem. Those wavelengths that potentially may not be available are defined as *OSW*, (Obstruct Sensitive Wavelength). Being N the number of network changes needed to trigger and update message and *Tp* (threshold percentage) being a percentage of N, a certain λ_i is defined as *OSW* on a link when the number of available wavelengths of this color is lower or equal to the T_p value. The *OSW* definition is extended to include the routing inaccuracy problem in the path selection process. Thus a new parameter is defined, $OSW_i\ (L,\ F)$ where L is the number of links where λ_i has been defined as *OSW* and F is the minimum value of available λ_i along the lightpath. Hence, L represents the *degree of obstruction* and F the *degree of congestion* of the path. The weight associated to each link is represented by the factor *L/F*. This factor stands for a balance between the number of potentially obstructed links and the real congestion. Moreover, in order to avoid those paths that are either widest (in terms of wavelength availability) but too long or shortest but too narrow, the weight factor of each path is modeled by F_p according to

$$F_p = H\left(\frac{L}{F}\right) \tag{1}$$

being H the path length. Then, *ALG3* selects that λ in the pre-selected k-shortest path minimizing the F_p value. *ALG3_H* modifies the *ALG3* behavior to be applied to hierarchical networks. This implies two main differences regarding a flat network structure. The former, the *OSW (L,F)* value can be computed on each hierarchical level. Hence, the expression used so far to model the weight factor F_p of each path must be adapted to these different *OSW (L,F)* values. The new weight factor is F_{p_H} and can be computed according to

$$F_{p\_H} = \sum_{i=1}^{n} F_p^i \tag{2}$$

where n is the number of hierarchical levels and $F_p^{\,i}$ is the F_p parameter per each hierarchical level. The selected wavelength will be that minimizing F_{p_H}.

The latter, *bypass-paths* may be computed on each hierarchical level. Meanwhile the ingress node for each *RA* must compute the route and the required *bypass-paths* along its network, the source node receiving the call request must compute the path to the destination node and the required *bypass-paths* on each hierarchical level.

III. Optimizing the Network Performance

This paper proposes both a new aggregation scheme and a new routing algorithm to address the routing inaccuracy problem in a hierarchical optical transport network.

A. Aggregation Scheme.

Consider a network consisting of Q *OXCs*. Each node is assumed to have a fixed number of ports. According to the proposed hierarchical structure, an optical network is divided into *M RAs* connected by border *OXCs*, each one composed of a set of *OXCs* with similar characteristics. Let $G(Q,U)$ describe the given physical network, where Q is a set of *OXCs* and U is a set of links (i.e. fibers) connecting the nodes. Let $g(q,u)$ describe the given physical *RA*, where q is the set of nodes (*OXCs*) in the *RA* and u is a set of links connecting the nodes within the *RA*. Therefore, $g \in G$, $q \in Q$ and $u \in U$. Assuming multifiber links, each fiber supports c different wavelengths, i.e. from λ_1 to λ_c. Moreover, we consider that wavelength conversion does not exist in any *OXC*. Thus, an incoming call is associated to the same wavelength color along the lightpath.

Generally speaking, aggregation schemes work as follows: Firstly, a *RA* pre-computes all the lightpaths existing between all border nodes along with the QoS parameters allocated to each lightpath. Secondly, an aggregation scheme summarizes this information reducing the amount of data to be flooded throughout the physical network. Finally, the aggregate information from each *RA* is grouped in a topology database, which will be used by a source node to compute an end-to-end lightpath.

We propose the following network parameters for optical networks: D as the propagation delay in a link which is proportional to the fiber distance between two nodes and W_p as the number of available wavelength of each color in a link.

According to these QoS parameters, we propose a new aggregation scheme for an *ASON*, named *Lightpath Aggregation Scheme* (*LAS*). The aggregation process performed in this scheme turns out two QoS parameters, the aggregated delay and the aggregated number of available wavelengths.

Lightpath Aggregation Scheme: Lightpath Aggregation Scheme (*LAS*) consists in pre-computing all possible lightpaths existing between two border nodes in the same *RA*. According to the aggressive mode, *LAS* chooses the best value of each QoS parameter and associates them to a pair border node. The process for each parameter is as follows:

Aggregated Delay (D_{ij}):

1. Compute all the lightpaths from node i to node j.
2. Add the propagation delay of each link for each lightpath.
3. Select the minimum value among the values computed in the step 2.

Aggregated number of available wavelength for a λ_p (W_p^{ij}):

1. Compute all the lightpaths from node i to node j.
2. Select the minimum number of wavelength per color that is available in each path.
3. Select the maximum value among the values computed in the step 2.

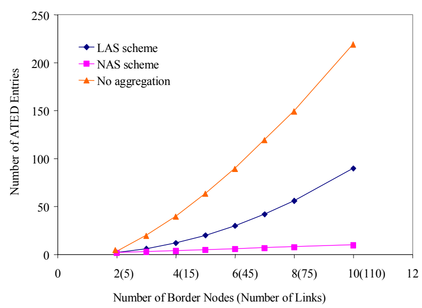

Fig. 2. Comparison between *LAS* and *NAS* and no aggregation

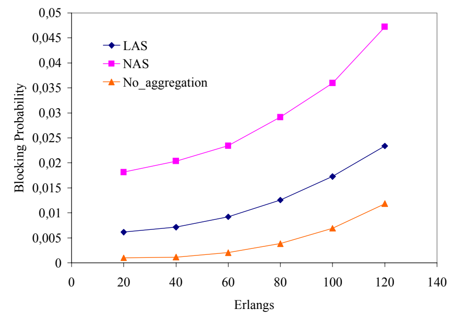

Fig.3. Blocking probability with/without aggregation applying the First-Fit

Formally, the aggregated delay and available wavelength are defined as follows.

$$D_{ij} = \min_{\forall R_{ij}} \left[\sum_{l \in R_{ij}} D(l) \right] \quad (3)$$

$$\underset{p=1..c}{W_p^{ij}} = \max_{\forall R_{ij}} \left\{ \min_{l \in R_{ij}} \left[W_p(l) \right] \right\} \quad (4)$$

where, R_{ij} is a lightpath between border node i and j, l is a link between two nodes belonging to R_{ij}, $W_p(l)$ is the number of wavelengths of color p available in a certain link l, and c is the number of colors per fiber.

B. *Routing Algorithm*

As mentioned in Section D, the *ALG3_H* is an *ALG3* extension to be applied to hierarchical networks. Thus, *ALG3_H* selects the proper wavelength according to the F_{p_H} value on the shortest path. One of the differences between *ALG3* and *ALG3_H* is that while k-shortest pats are precomputed by the *ALG3* only the shortest one is computed by *ALG3_H*. In this paper we propose an extension of *ALG3_H* to show the impact of selecting k-shortest paths on the connection blocking for a hierarchical network structure. Therefore, we name *ALG3_H/k* those algorithms selecting the proper wavelength among the precomputed k-shortest path routes.

IV. PERFORMANCE EVALUATION

We use the network topology shown in Fig. 1 to evaluate our proposal. We suppose a 5-fiber topology, with 16 wavelengths on all the fibers. Call arrivals are modeled by a Poisson distribution and the connection holding time is assumed to be exponentially distributed.

The effects of aggregating the network state information on the network performance are measured in terms of both the *ATED* size and the blocking probability. Fig. 2 indeed illustrates the effects of using the proposed aggregation scheme in terms of entries of the *ATED*. It shows a comparison between the *ATED* size produced when applying aggregation schemes, *NAS* and *LAS*, and the *ATED* size produced when an aggregation scheme is not used. In the first case, the *ATED* size depends on the number of ingress/egress nodes on the network. In the second case, the *ATED* size depends on the number of links on the whole network, therefore producing a database size larger than the first case. Moreover, we can observe in Fig. 2 that the *LAS* scheme produces an *ATED* larger than the *NAS* scheme. This is due to the fact that while the *ATED* size based on the *LAS* scheme depends on the number of routes between all the border nodes, the *ATED* size based on the *NAS* (explained in Section A) only depends on the number of border nodes.

On the other hand, Fig. 3 shows the impact of using aggregation schemes on the blocking probability. The routing algorithm used to select the routes is based on applying the *First-Fit* (*FF*) heuristic on the shortest path. We can observe that compared to the case when there is not information aggregation, while the *NAS* drives to a blocking increment of 3.52% the *LAS* increments the blocking only in a 1.18% (measured when the network is heavily loaded). Therefore the reduction obtained by the *LAS* compared to the *NAS* is about a 2.32%. The choice between one of the two schemes depends on two factors: the required information accuracy and the cost in terms of signaling overhead. While *LAS* provides better accuracy than *NAS*, *NAS* produces less signaling overhead than *LAS*.

In Fig.4 we compare the blocking probability obtained by the *LAS* and *NAS* schemes when applying both the *ALG3_H/1* and the *FF*. In fact, *LAS* and *NAS* schemes perform better when the *ALG3_H/1* is also included. Compared to the *FF* heuristic a reduction on the blocking probability of 1.25% and 0.84% is obtained (under the higher network load) by the *NAS* and the *LAS* respectively when applying *ALG3_H/1*. Hence, best results are obtained when *LAS* and *ALG3_H/1* are applied jointly, i.e. *LAS-ALG3_H/1*.

In addition, Fig.5 shows the reduction obtained on the blocking probability when k-shortest paths are precomputed. The value of k ranges from 1 to 3 therefore *LAS-ALG3_H/1*, *LAS-ALG3_H/2* and *LAS-ALG3_H/3* are evaluated for the *LAS* scheme. After carefully analyzing obtained results we can con-

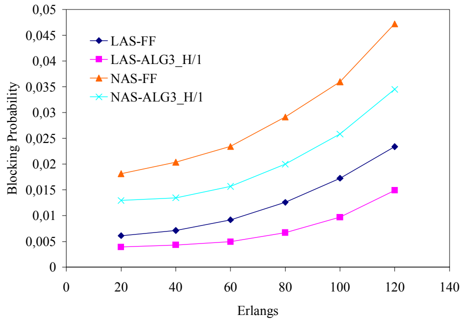

Fig. 4. Blocking probability for the First_Fit and the ALG3_H/1

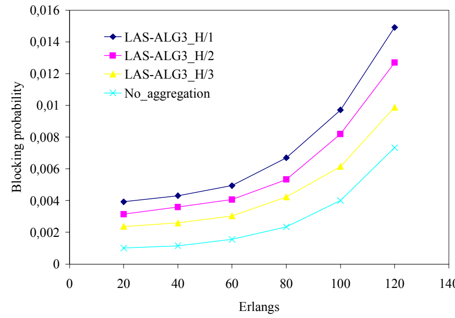

Fig. 5. Blocking probability as a function of the k value

clude that the benefits because of considering k-shortest paths are more significant as network load raises. Being placed indeed on the heavily network load, the difference on the blocking probability obtained by the *LAS-ALG3_H/1*, *LAS-ALG3_H/2* and *LAS-ALG3_H/3* compared to the situation where there is not aggregation is of 0.76%, 0.54% and 0.25% respectively. Thus, the blocking probability increment because of applying an aggregation scheme to achieve network scalability is substantially reduced when the *ALG3_H/k* is applied.

V. CONCLUSIONS

According to the GMPLS routing functions needed to provide ASON with hierarchical routing, in this paper we decompose the hierarchical routing problem into three main issues: the aggregation process used to reduce disseminated information throughout the network; the update policy used to keep network state databases perfectly updated; and the lightpath selection process assuming the potential network state inaccuracy introduced by both the aggregation process and the update policy. Therefore, we propose a new aggregation scheme, named *LAS,* a new update policy and a new routing algorithm named *ALG3_H/k* to provide a hierarchical optical transport network with better accuracy and scalability. It is shown by simulation the benefits of applying both mechanisms, i.e., obtaining a reduced increment of the blocking probability while substantially reducing the signaling overhead. We can say that the scalability improvement in terms of the *ATED* size is obtained by the *LAS*, while the negative effect on the blocking probability because of aggregating the network state information is overcome by the *ALG3_H/k*.

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