An Integrated Scheme for Multilayer Network Restoration

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***Abstract*— An integrated multilayer resilience scheme represents an efficient solution for guaranteeing resilience of *peer-to-peer* network architectures featuring a unified control plane, such as the emerging IP/GMPLS/WDM architecture. In this study a single integrated multilayer restoration scheme, namely the *Stochastic Integrated Multilayer Restoration* (*SIMuR*) scheme, is proposed. The SIMuR scheme stochastically chooses, based on the current network status information, along which path and at which layer, i.e., granularity, failed lightpaths are restored. Simulation results show that the SIMuR scheme quickly approaches, for increasing granularity, the average restoration probability lower bound while limiting the required grooming and signaling overheads.**

***Keywords*— Resilience, Multilayer restoration, GMPLS.**

I. Introduction

The assignment of *resilience*[1] functionalities to the network layers and their coordinated activation upon failure represent one of the issues in designing *multilayer networks*. This problem is also commonly known as *Multilayer Resilience Problem* (*MRP*) [1], [2]. Several solutions of the MRP have been proposed for multilayer networks in which lower layers work as server of upper network layers, such as IP over ATM and IP over WDM *overlay* architectures [3], [4].

The introduction, through the GMPLS framework [5], of *peer-to-peer* network architectures equipped with a single common control plane makes a *single integrated multilayer approach* for resilience an attractive MRP solution [1]. The single integrated multilayer approach for network resilience is based on a *single integrated multilayer resilient scheme* having full overview of all the network layers and able to decide when and in which layer to recover the disrupted traffic [1].

In this study a Stochastic Integrated Multilayer Resilience scheme (*SIMuR*) is proposed as a single integrated restoration scheme for dynamic multilayer peer-to-peer networks based on the IP/GMPLS/WDM architecture. The SIMuR scheme combines the concept supported by the GMPLS framework of *hierarchical Generalized Label Switched Paths (GLSPs)* [5] and the restoration path stochastic selection proper of the Stochastic Preplanned Restoration scheme with Proportional Weighted path choice (SPR-PW scheme) proposed in [6] [2].

Numerical results show that the SIMuR scheme is able to closely approximate the restoration blocking probability lower bound. Moreover the grooming capabilities necessary at the network nodes for demultiplexing and multiplexing finer granularity [3] GLSPs are limited. If network nodes are not equipped with grooming capabilities the average restoration blocking probability is still less than the one guaranteed by the single (optical) layer SPR-PW scheme. In the end, results show that the SIMuR scheme, if equipped with the proper restoration signaling scheme, requires limited restoration signaling overheads.

II. The Stochastic Integrated Multilayer Restoration Scheme

The Stochastic Integrated Multilayer Restoration (SIMuR) scheme is proposed for recovering failed lightpaths from a single physical link failure. The SIMuR scheme can be classified as a preplanned restoration scheme because only upon failure occurrence the restoration path is selected from a set of pre-computed restoration paths and spare resources along the chosen path are reserved. The SIMuR scheme is based on the concept of hierarchical GLSPs that implies that a lightpath can be considered as the multiplexing of finer granularity connections (e.g., Gigabit Ethernet, ATM, SONET/SDH connections) generally called *lower-order GLSPs*.

In the SIMuR scheme, once the connection source node receives a failure notification, it stochastically assigns each lower-order GLSPs, in which the disrupted lightpath is demultiplexed, to the pre-computed restoration paths independently. The stochastic choice of the restoration path is based on the probabilities computed using the available traffic statistics, as presented in [6]. By stochastically choosing the restoration path along which each lower-order GLSP multiplexed in a failed lightpath must be restored, the SIMuR scheme establishes also at which layer (e.g., granularity) the failed lightpath is recovered.

Two different restoration signaling schemes to reserve link resources for restoring disrupted GLSPs are implemented. The first one, called *GLSP-oriented*, uses a separate signaling instance for each GLSP to be restored. The second scheme, called *Path-oriented*, is based on the restoration signaling scheme, proposed in [7] as *aggregation over common path*. Specifically a single signaling instance is required for all the GLSPs belonging to the same source-destination pair restored along the same restoration path.

III. Performance Evaluation Criteria

The evaluation of the SIMuR scheme efficiency is based on three main criteria: the *average restoration blocking*

[1] Resilience is commonly intended as the ability of overcoming network failures.

[2] In [6] the SPR-PW scheme was introduced as Preplanned Weighted Restoration (PWR) scheme.

[3] Granularity is determined by the protocol traffic unit at that particular layer.

probability, the *necessary node grooming capability* and the *restoration signaling overhead*.

Consider a graph $G(\mathcal{N}, \mathcal{L})$ with $|\mathcal{N}|$ nodes and $|\mathcal{L}|$ bidirectional links that represents the network. The average restoration blocking probability $\overline{Pr_b}$, is defined as the average, over all the possible single link failures, of the ratio between the number of unrestored GLSPs, $GLSP_u^{\bar{l}}$, and the total number of GLSPs, $GLSP_f^{\bar{l}}$, multiplexed in the lightpaths disrupted by the failure of link $\bar{l}$:

$$\overline{Pr_b} = \sum_{\bar{l}=0}^{|\mathcal{L}|-1} Pr_f^{\bar{l}} \cdot \frac{GLSP_u^{\bar{l}}}{GLSP_f^{\bar{l}}}, \tag{1}$$

where $Pr_f^{\bar{l}}$ is the failure probability of link $\bar{l}$.

The necessary grooming capability at node m is defined as the ratio between the number of output ports at node m in which the grooming is necessary, P_m^G, and the total number of output port at node m, P_m:

$$G_m = \frac{P_m^G}{P_m}. \tag{2}$$

The value of P_m^G is calculated as $P_m^G = \sum_{k=1}^{P_m} l_k^{G,m}$, where $l_k^{G,m}$ is a binary variable assuming the value of 1 if grooming at the k-th output port of node m is necessary and 0 otherwise. The value of $l_k^{G,m}$ is determined as follows. Let B_{l_i,l_k}^m be the sum of the bandwidth, expressed in fraction of a wavelength, of the GLSPs to be switched at node m from the i-th ingress port to the k-th output port. Grooming on the k-th output port of node m is necessary, i.e., $l_k^{G,m} = 1$, if wavelengths on link l_k outgoing from the k-th output port cannot be partially occupied. That is if $\sum_{i=0, i\neq k}^{P_m} \lceil B_{l_i,l_k}^m \rceil > c_{l_k}$, where c_{l_k} is the total capacity offered by the wavelengths on link l_k and B_{l_0,l_k}^m is the capacity occupied by GLSPs generated at node m and outgoing from link l_k.

The restoration signaling overhead is represented by the number of hops spanned by the reservation messages utilized for GLSPs restoration. The average GLSP-oriented signaling overhead, O_{GLSP}, and the average Path-based signaling overhead, O_{Path}, are defined, respectively, as:

$$O_{GLSP} = \frac{1}{|\mathcal{L}|} \cdot \sum_{\bar{l}=0}^{|\mathcal{L}|-1} \sum_{s,d} \sum_{i=1}^{R} 2 \cdot h_{r_{s,d}^i} \cdot GLSP_{f,r_{s,d}^i}^{\bar{l}}, \tag{3}$$

$$O_{Path} = \frac{1}{|\mathcal{L}|} \cdot \sum_{\bar{l}=0}^{|\mathcal{L}|-1} \sum_{s,d} \sum_{i=1}^{R} 2 \cdot h_{r_{s,d}^i} \cdot N_i. \tag{4}$$

In Eq. (3) $GLSP_{f,r_{s,d}^i}^{\bar{l}}$ is the number of disrupted GLSPs between the node pair (s, d) that are restored along path $r_{s,d}^i$. In Eq. (4) N_i is a binary variable assuming the value of 1 if one or more GLSPs have been assigned to restoration path $r_{s,d}^i$ and 0 otherwise. In both Eq. (3) and (4) $h_{r_{s,d}^i}$ represents the number of links spanned by the i-th restoration path $r_{s,d}^i$, R is the number of available restoration paths, and the factor 2 takes into account the reservation message round-trip.

IV. Results

The SIMuR scheme has been evaluated by means of a custom built simulator on the network depicted in Fig. 3 consisting of 6 nodes and 9 bidirectional links. Each network node is assumed to have full wavelength conversion capabilities. The total capacity of each link, c_l, is set to 32 wavelengths. All the working lightpaths between the source-destination pair (s, d) are routed along the shortest path between node s and node d. The available restoration paths for lightpaths between the node pair (s, d) consist of the two remaining mutually link disjoint shortest paths between the pair (s, d). Each lightpath is assumed to result from the multiplexing of a number of n lower-order GLSPs with equal capacity. For each single link failure 10 instances of the SIMuR scheme are performed. The link failure probability $Pr_f^{\bar{l}}$ is uniformly distributed among all the possible single link failure scenarios (i.e., $Pr_f^{\bar{l}} = 1/|\mathcal{L}|$). The simulation results are averaged out of 1500 traffic scenarios at a fixed average network throughput. The average network throughput is defined as the ratio between the network capacity utilized by the working lightpaths and the total available network capacity.

Fig. 1 shows that when each network node is equipped with the necessary grooming capabilities the SIMuR scheme closely approximates the optimal restoration blocking probability obtained by the solution of the Linear Programming (LP) formulation of the Path Restoration Routing (PRR) problem [8]. The, so called, *LP scheme* maximizes the number of GLSPs restored utilizing the spare capacity available along the restoration path links under the assumption that failed lightpaths can be demultiplexed in an infinite number of GLSPs.

As shown in Fig. 2, for the considered network scenario, the necessary node grooming capability is not elevated (less than 0.1 for each network node). When no network node implements grooming capability, the average restoration blocking probability increases due to the blocking of GLSPs that require grooming at intermediate nodes (Fig. 4). However the SIMuR scheme is still able to obtain a lower average restoration blocking probability than the one obtained by the SPR-PW scheme. This behavior can be explained by the fact that the statistics of the assignments to the preplanned restoration paths of the GLSP, in which a failed lightpath is demultiplexed, tend, at the limit for an infinite number of GLSPs, to the choice probabilities computed for each restoration path that minimize spare resource contention.

Fig. 5 shows that Path-oriented signaling is more scalable than GLSP-oriented signaling in function of the number of GLSPs multiplexed into one failed lightpath. As depicted in Fig. 5 the average signaling overhead required by the GLSP-oriented signaling linearly increases in function of the number of GLSPs multiplexed into one failed lightpath while the average Path-oriented signaling overhead slightly increases. This behavior could be expected by comparing Eq. (3) and Eq. (4). Furthermore Fig. 6 shows a reduction of the signaling overhead for the Path-oriented signaling scheme for increasing average network throughput. This behavior is due to the increasing number of busy recovery paths where no signaling messages are sent.

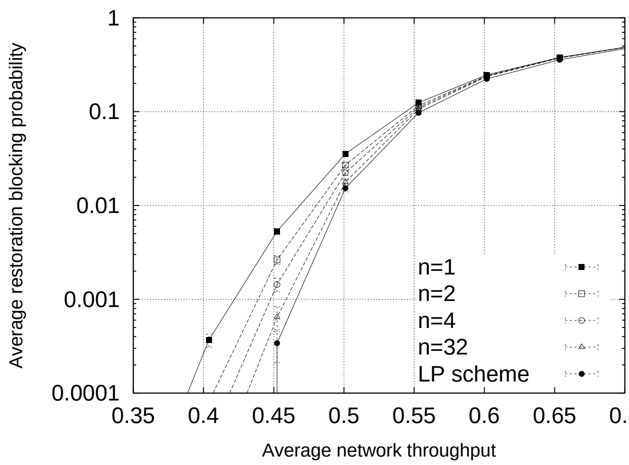

Fig. 1. Blocking probability with necessary node grooming capability

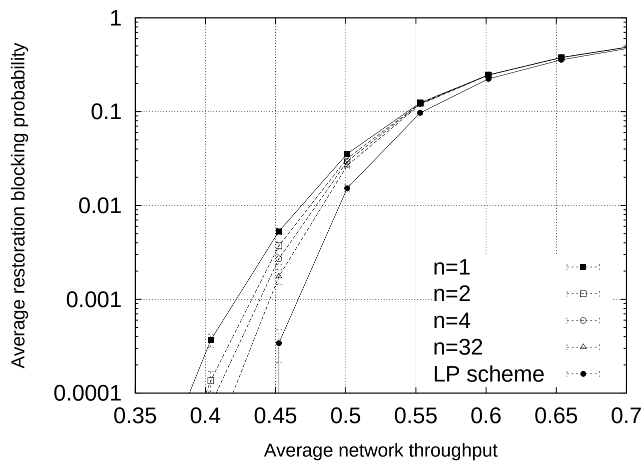

Fig. 4. Blocking probability without node grooming capability

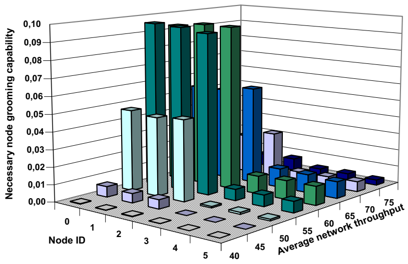

Fig. 2. Average necessary node grooming capability $n = 8$

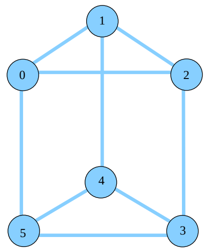

Fig. 3. Test network

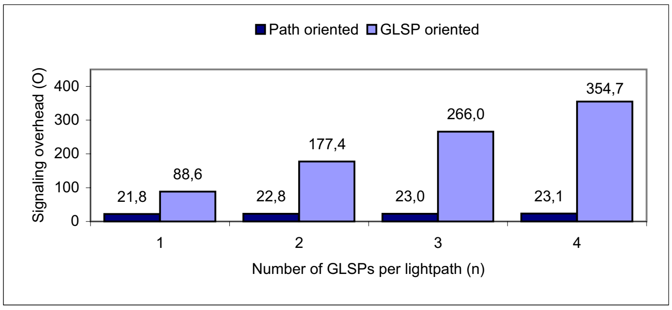

Fig. 5. Signaling overhead at average network throughput 0.55

V. Conclusion

This paper presented an approach for the implementation of a single integrated multilayer restoration scheme applicable to dynamic multilayer network architectures, such as IP/GMPLS/WDM networks. The SIMuR scheme exploits the possibility of stochastically choosing the layer, i.e., the granularity, at which failed lightpaths are restored. Simulation results showed that the proposed scheme closely approximates the average restoration blocking probability optimal values while keeping limited the grooming capability necessary at each network node and the amount of restoration signaling overhead.

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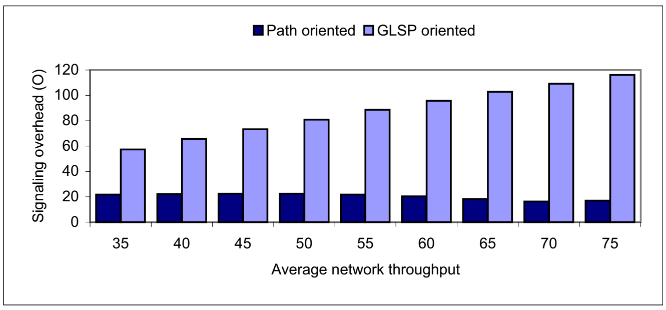

Fig. 6. Signaling overhead with $n = 1$