A Path Protection Algorithm Based on OSNR for All-Optical Networks with Relaxed Restriction Limitation

Rodrigo C. de Freitas
Amazonas State University (UEA)
69065-020, Manaus – AM, Brazil
e-mail: {rcfreitas@uea.edu.br

Carmelo J. A. Bastos-Filho and
Daniel A. R. Chaves
Polytechnical School of Pernambuco
University of Pernambuco (UPE)
52720-001, Recife – PE, Brazil
e-mail:{carmelofilho,danielchaves}@poli.br

Joaquim F. Martins-Filho
Department of Electronics and Systems
Federal University of Pernambuco (UFPE)
50740-550, Recife – PE, Brazil
e-mail: jfmf@ufpe.br

***Abstract*—In this paper we propose a variation of the shared backup path protection algorithm for all-optical networks, called Limited Shared Path Protection based on OSNR (*LiSPP-OSNR*), proposed by Freitas *et al.*. In this version, we include a controlled relaxation of the fundamental restriction, *i.e.* we define the maximum number of violations to the fundamental restriction in order to achieve a good trade-off between blocking probability, protection ratio and vulnerability ratio. We call it Relaxed Restriction Limited Shared Path Protection based on OSNR (*ReLiSPP-OSNR*). We use an analytical model to evaluate the physical layer impairments (PLIs) that considers the following: gain saturation, amplified spontaneous emission (ASE) noise depletion in the optical amplifiers, crosstalk in the optical switches, four-wave mixing, polarization mode dispersion (PMD) and the chromatic dispersion in optical fibers. We compare both policies (*LiSPP-OSNR* and *ReLiSPP-OSNR*)for protection ratio, vulnerability ratio and blocking probability metrics. The policy that uses relaxed restriction presents best performance.**

I. INTRODUCTION

The mechanisms to provide resilience to optical networks are Protection and Restoration. The main advantage of Protection schemes over Restoration schemes is the guarantee of service to the protected lightpaths upon a limited number of simultaneous failures. Protection schemes can be classified in dedicated and shared protection. In the first type, spare resources are just used once at a time by the working lightpath that is attending to a call request, *i.e.*, the resources that are being used for backup lightpaths can not be shared by any other working lightpath. This guarantees the resilience of the protected lightpaths, but requires more network resources to fully protect working lightpaths. The shared protection scheme aims to mitigate this need for an available link-disjoint backup lightpath. This is implemented by sharing spare resources of backup lightpaths to protect several working lightpaths simultaneously [1].

The shared protection is considered as an efficient scheme to provide resilience when the following restriction is adopted: if two working lightpaths are not link-disjoint, then their respective backup lightpaths have to be link-disjoint from each other [1]. This strategy was explored by Guo *et al.* [2], Rosa *et al.* [3], Fumagalli *et al.* [4] and Shao *et al.* [5], [6]. This restriction guarantees that any working lightpath can be properly restored if a single link failure occurs in the network [3].

Since this restriction is too strong for dynamic networks, it is common to have a relaxation in order to achieve a reasonable blocking probability with a maximum number of protected working lightpaths [7]. This relaxation is often used together with the sharing limit policy, which allows to share some of the wavelengths in some of the links for backup lightpaths. It is important to limit the maximum number of times this wavelength can be shared, since it has direct influence on the trade-off between protection rate, vulnerability rate and blocking probability of the network [7].

Freitas *et al.* [7] proposed an efficient algorithm to dynamically assign shared backup lightpaths based on the maximum Optical Signal-to-Noise-Ratio (*LiSPP-OSNR*) that uses the sharing limit policy, but does not obey the fundamental restriction. This algorithm introduces two criteria in the search for a backup lightpath: i) the number of times that an wavelength can be used to protect a set of primary lightpaths is limited (sharing limit - SL). This strategy is already considered in [2]–[6] . For example: $SL = 0$ means that each wavelength in each link may be used only once as a backup lightpath (*dedicated protection*); $SL = 1$ means that each wavelength in each link may be used for two backup lightpaths, and so on. We also call this strategy as sharing limit policy (SLP) and it helps the optical network designer to choose the optimal trade-off between blocking probability, protection and vulnerability; ii) the backup lightpath has to present the maximum OSNR on the destination node. The *LiSPP-OSNR* algorithm disregards the fundamental rule of the shared path protection.

In this paper, we propose a modification to the *LiSPP-OSNR* algorithm to include a controlled relaxation of the fundamental restriction, the *ReLiSPP-OSNR*. In this case, we define the maximum number of violations to the fundamental restriction, *i.e.* the Restriction Limit (RL), in order to achieve a good trade-off between blocking probability, protection ratio and vulnerability ratio. For instance, $RL = 0$ means that the fundamental restriction is fully respected, whereas $RL = n$ means that only up to $n - 1$ working lightpaths that pass through the same link can share the same backup lightpaths. The original *LiSPP-OSNR* algorithm has $RL = \infty$.

The rest of the paper is organized as follows: In Section II, we present an example of the Relaxation of the Restriction using Restriction Limit concept. In Section III, we present our contribution. In Section IV, we describe the simulation setup and the physical layer impairments considered in this paper. In Section V, we show some simulation results comparing our proposal and the original *LiSPP-OSNR*. In Section VI, we give our conclusions.

II. EXAMPLE OF THE RELAXATION OF THE RESTRICTION USING RESTRICTION LIMIT

This Section presents an example of the proposed mechanism to alleviate the fundamental shared protection restriction using the Restriction Limit (RL), as discussed in Section I. The dynamics of this restriction is implemented according the following example.

Consider Figure 1 and suppose that two lightpaths are established, C_1 in working lightpath $A-B-C-D$ and C_2 in working lightpath $B-C-D$. If C_1 establishes its backup lightpath in route $A-F-E-D$ in wavelength λ_1, then C_2 can not establish a backup lightpath in the same wavelength of C_1. It occurs because, although there is a link-disjoint backup route $B-A-F-E-D$, the links $A-F$, $F-E$ and $E-D$ in the backup wavelength λ_1 are already used in the C_1 backup lightpath. This will violate the fundamental restriction.

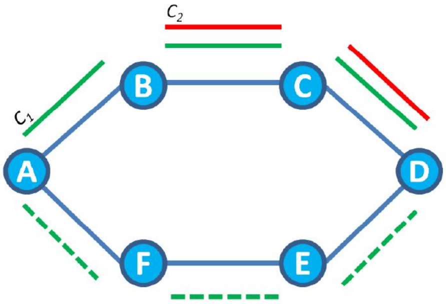

Fig. 1. Fundamental restriction of shared protection scheme.

On the other hand, if the fundamental restriction is relaxed, we can improve the optical network survivability capacity. In Figure 2, although C_1 and C_2 are sharing links and nodes in their respective working routes (solid lines), their backup routes (dotted lines) also share links, nodes and backup wavelength. This relaxation allows the protection of a higher number of calls. If a fail occurs in the link $A-B$ the call C_1 can use backup lightpath $A-F-E-D$ in wavelength λ_1. However it generates a vulnerability for the call C_2, *i.e.* if a second failure happens, the call C_2 will be lost. A worst situation can occur when a lightpath disputes by the protection resource with another working lightpath, preventing the recovery of one of them if a failure occurs. For example, if the link $B-C$ fails, only one of the working lightpaths (C_1 or C_2) will be restored.

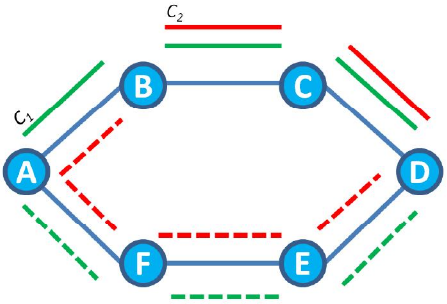

Fig. 2. Relaxation of the fundamental restriction of shared protection scheme.

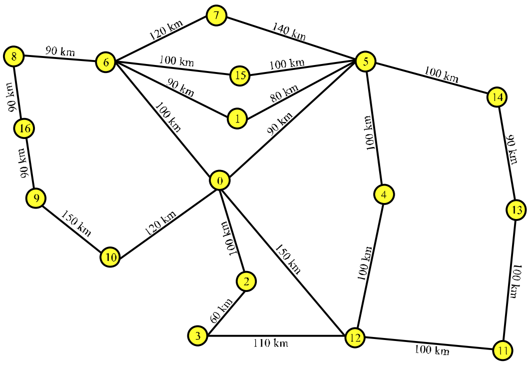

Fig. 3. Topology 1.

III. RELISPP-OSNR ALGORITHM

We propose in this paper the Restriction with Limited Shared Path Protection based on OSNR (*ReLiSPP-OSNR*) Algorithm. This algorithm is based on the fundamental restriction, that means that two working lightpaths sharing one or more links can not share the same backup lightpath. This algorithm uses a flexible approach, called as limited restriction policy (*LRP*), that uses the fundamental restriction but in a controlled manner, allowing more than one working lightpath to share the same backup lightpath. In this regard, we expect to increase the optical network survivability. Furthermore, the *ReLiSPP-OSNR* algorithm evaluates if the quality of transmission (QoT) of the backup lightpath is acceptable to establish it. In this paper we consider $SL = \infty$ for the *ReLiSPP-OSNR* Algorithm.

Algorithm 1 presents the pseudocode of *ReLiSPP-OSNR*. For each call request, the *ReLiSPP-OSNR* algorithm searches for a working lightpath γ which presents an acceptable QoT. If the working lightpath γ is found, the *ReLiSPP-OSNR* algorithm searches for a backup route β by using the following steps: (i) find the backup route (link-disjoint to γ) composed by the links $l_0, l_1, l_2, ..., l_i, ..., l_n$ that presents the best OSNR; (ii) check the availability of a wavelength w for all links belonging to the backup route (from the link l_0 to the link l_n); (iii) Build a list r with all other active working lightpaths that share any link with the current working route γ; (iv) Count in $qty_{(calls)}$ how many active working lightpaths of the list r use the same links of the current backup lightpath (composed by route β and wavelength w); (v) if the QoT of β is acceptable, the backup lightpath is accepted. It is important to remark that the working lightpaths may be established, even without a backup lightpath.

Algorithm 1: *ReLiSPP-OSNR* pseudocode.

```
for each call request do
    if (exists an available working lightpath $\gamma$) then
        for ($w$=0 to $W$) do
            Search for a backup route
              $\beta = (l_0, l_1, l_2, ..., l_i, ..., l_n)$ with higher
              OSNR;
            if (exist an available $w$) and (exist an
              available $\beta$) then
                Bulid list $r$;
                Count $qty_{(calls)}$;
                if ($QoT(\beta, w) = true$) and
                  ($qty_{(calls)} < RL$) then
                    Establish $\beta$;
                end if
            end if
        end for
    else
        Block call;
    end if
end for
```

IV. SIMULATION SETUP

All-optical networks generally operate with high transmission capacities and the signal remains in the optical domain between the edge nodes, *i.e.* the signal propagates along the core of the optical network without any optical-electrical-optical conversion. Because of the linear and nonlinear physical layer effects in optical fibers and the noise inserted by the network elements along the lightpaths, the $OSNR$ of the transmitted signal can be degraded, which have directly impact on the QoT [8]. Because of this, we used an analytical model, proposed by Pereira *et al.* [8], based on the $OSNR$ degradation to take into account the effect of gain saturation and ASE noise depletion in amplifiers, the chromatic dispersion, the coherent crosstalk in optical switches and the PMD and the residual chromatic dispersion [9] in optical fibers.

We performed our simulations using the network topology depicted in Figure 3. We considered a network load of 60 erlangs. The simulation parameters are listed in the Table I.

A. Metrics for network performance evaluation

- Protection ratio (pr): this metric represents the relative number of established primary lightpaths that has a backup lightpath. It is given by:

$$pr = \frac{\rho}{\rho + \mu}, \tag{1}$$

in which ρ is the number of connections with backup lightpaths and μ is the number of connections without backup lightpaths.

- Vulnerability ratio (vr): this metric represents the relative number of established primary lightpaths that become unprotected if a single link failure occurs. This metric is given by:

$$vr = \frac{\mu + \nu}{\mu + \nu + \rho'}, \tag{2}$$

in which ν is the number of connections that lost their backup lightpaths for others connections, after a link failure and ρ' is the number of connections that do not share backup resources with other connections or won the competition for resources. This metrics reflects the percentage of connections that will be recovered if a failure occurs.

- Blocking probability (bp): this metric represents the relative number of lost calls due to the lack of available wavelengths or the lack of QoT due to the physical layer impairments [9]. It is given by:

$$bp = \frac{\sigma}{\alpha}, \tag{3}$$

in which σ is the number of blocked calls and α is the total number of generated calls.

TABLE I
DEFAULT SIMULATION PARAMETERS.

Parameter	Value	Definition
P_{sat}	26 dBm	Amplifier output saturation power.
$OSNR_{in}$	40 dB	Input optical signal-to-noise ratio.
$OSNR_{QoT}$	23 dB	Optical signal-to-noise ratio for QoT criterion.
B	40 Gb/s	Transmission bit rate.
B_o	100 GHz	Optical filter bandwidth.
Δf	100 GHz	Channel spacing.
λ_i	1529.56 nm	The lower wavelength of the grid.
λ_0	1557 nm	Zero dispersion wavelength.
α	0.2 dB/km	Fiber loss coefficient.
L_{Mux}	2 dB	Multiplexer loss.
L_{Demux}	2 dB	Demultiplexer loss.
L_{Switch}	2 dB	Optical switch loss.
δ	10%	Maximum pulse broadening.
W	20, 40	Number of wavelengths per link, considered in each simulation scenario.
F_0 (NF)	3.162 (5 dB)	Amplifier noise factor (Noise figure).
$\Delta\lambda_{tx}$	0.05 nm	Transmitter laser linewidth.

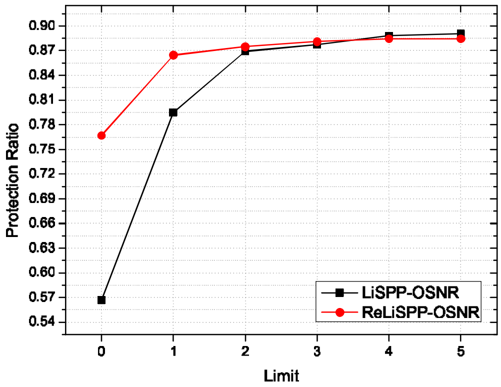

Fig. 4. Protection ratio versus sharing limit for the *LiSPP-OSNR* and restriction limit for the *ReLiSPP-OSNR*, 20 wavelengths per link and 60 erlangs.

V. RESULTS

In this section we present the results obtained by the *ReLiSPP-OSNR* and the comparison with the *LiSPP-OSNR* algorithm, proposed by Freitas *et al.* [7].

Figure 4 shows the protection ratio as a function of the sharing limit (*SLP*) and restriction limit *RLP*, considering 20 wavelengths per link. One can observe that for the limits 0 and 1, the *RLP* presents higher protection ratio than the *SLP*. It occurs because *RLP* evaluates the existence of conflicts among the backup resources. For limit values higher than $SL = RL = 2$, the protection ratios are similar and assume values around 87%.

Our hypothesis for the behavior depicted in Figure 4 is detailed as follows. Figure 5 illustrates the dynamics of the *SLP* in the use of the optical network resources for the following scenario: (i) the protection scheme is dedicated and there is only the wavelength λ_1 available to be used as backup in this topology; (ii) the call A is established in route $5-6$, before the call B request; (iii) the second shortest route ($5{-}7{-}8{-}6$) is returned to be used as backup route and it is evaluated the availability of backup wavelength. As a result of this policy, in this scenario, we have the following: (i) the call A uses as a backup ligthpath the route $5-7-8-6$ in wavelength λ_1; (ii) for the call B is not established a backup lightpath, because there is no more available backup wavelength in route $5-7-8-6$; (iii) in this particular scenario, only half of the calls is protected.

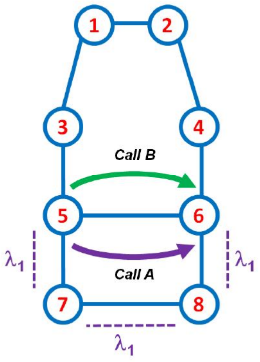

Fig. 5. Sharing limit policy.

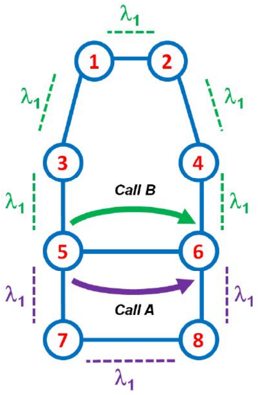

Fig. 6. Restriction limit policy.

Figure 6 illustrates the dynamics of the restriction limit policy in the use of the optical network resources for the following scenario: (i) the protection scheme is dedicated and there is only the wavelength λ_1 available to be used as backup; (ii) the call A is established in route $5-6$, before the call B request; (iii) the calls A and B share links in their working routes, therefore their backup routes has to be disjoint from each other. As a result of this policy, in this scenario, we have: (i) for the call A it is established a backup ligthpath in route $5-7-8-6$ and wavelength λ_1; (ii) for the call B it is established a backup ligthpath in route $5-3-1-2-4-6$ and wavelength λ_1; (iii) in this particular scenario, all the calls are protected.

Figure 7 presents the vulnerability ratio as a function of the sharing limit and restriction limit policies, considering the Topology 1 with 20 wavelengths per link. The $SL = RL = 0$ represent the dedicated protection scheme, therefore the vulnerabibilty ratio is zero. From $SL = RL = 1$ on, the restriction limit policy presents the best performance, *i.e.*, it generates the lowest vulnerability ratios.

Figure 8 presents the blocking probability as a function of the sharing limit and restriction limit, considering the Topology 1 with 20 wavelengths per link. Again, the restriction limit policy presents better performance than the sharing limit policy, reaching the lowest blocking probabilities. It occurs because the restriction limit policy compacts the use of wavelengths, *i.e.*, less wavelengths are used to protect a call. Considering the Topology 1 and 20 wavelengths per link, we have the following results: (i) the sharing limit policy shares 63% more wavelengths than the restriction limit policy for $SL = RL = 0$; (ii) the sharing limit policy shares 72% more wavelengths than the restriction limit policy for $SL = RL = 3$; (iii) the sharing limit policy shares

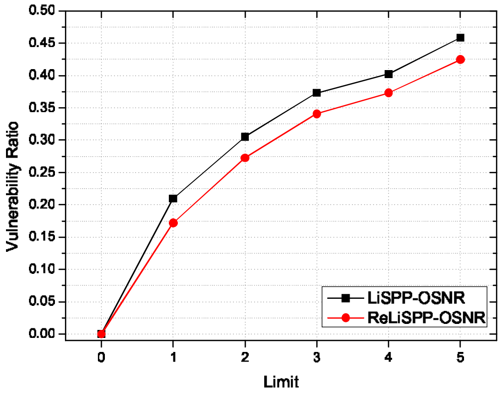

Fig. 7. Vulnerability ratio versus sharing limit for the *LiSPP-OSNR* and restriction limit for the *ReLiSPP-OSNR*, for 20 wavelengths per link and 60 erlangs.

64% more wavelengths than the restriction limit policy for $SL = RL = 5$.

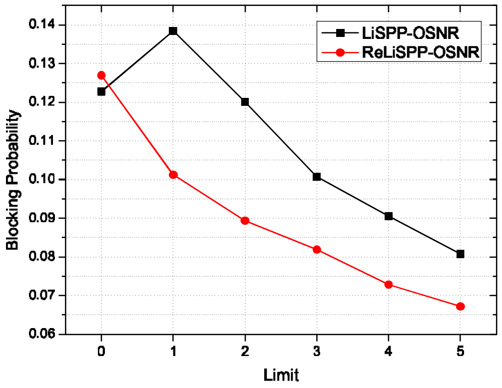

Fig. 8. Blocking probability versus sharing limit for the *LiSPP-OSNR* and restriction limit for the *ReLiSPP-OSNR*, for 20 wavelengths per link and 60 erlangs.

We also evaluated the performance of the *ReLiSPP-OSNR* and *LiSPP-OSNR* Algorithms in the scenario considering 40 wavelengths per link. The results were similar to the scenario for 20 wavelengths per link.

VI. CONCLUSIONS

In this paper we proposed a novel shared backup path protection algorithm, which takes into account the signal degradation. We named our proposal, based in the restriction limit policy, *ReLiSPP-OSNR* and we compared it with the *LiSPP-OSNR* algorithm based in the sharing limit policy, proposed in a previous work. For the investigated scenarios the *ReLiSPP-OSNR* algorithm presented the best results.

ACKNOWLEDGMENT

The authors acknowledge the financial support from FACEPE, FAPEAM, CNPq, CAPES, UFPE, UEA and UPE for scholarships and grants.

REFERENCES

[1] C. Ou and B. Mukherjee, *Survivable Optical WDM Networks*, 1st ed., ser. Optical Networks Series. Springer, 2005.

[2] L. Guo, X. Wang, J. Cao, and X. Zheng, "Recovery escalation with load balancing and backup resources sharing in survivable WDM optical networks," *Photonic Network Communications*, pp. 393–399, 2009.

[3] S. Rosa, A. Drummond, and N. Fonseca, "Path protection wdm networks with impaired-transmission," *Photonic Network Communications*, vol. 19, no. 2, pp. 212–222, 2010.

[4] A. Fumagalli, M. Tacca, F. Unghvary, and A. Farago, "Shared path protection with differentiated reliability," in *IEEE International Conference on Communications*, vol. 4, August 2002, pp. 2157–2161.

[5] X. Shao, L. Zhou, X. Cheng, W. Zheng, and Y. Wang, "Best effort shared risk link group (srlg) failure protection in WDM networks," in *IEEE International Conference on Communications*, May 2008, pp. 5150–5154.

[6] X. Shao, Y. Bai, X. Cheng, Y. Yeo, L. Zhou, and L. Ngoh, "Best effort SRLG failure protection for optical WDM networks," *Journal of Optical Communications Network*, vol. 3, no. 9, pp. 739–749, September 2011.

[7] R. Freitas, E. Santos, D. Chaves, H. Pereira, C. Bastos-Filho, and J. Martins-Filho, "A path protection algorithm based on osnr for all-optical networks with wavelength sharing limitation," in *International Conference on Transparent Optical Networks ? ICTON*, 2012.

[8] H. A. Pereira, D. A. R. Chaves, C. J. A. Bastos-Filho, and J. F. Martins-Filho, "Osnr model to consider physical layer impairments in transparent optical networks," *Photonics Network Communications*, vol. 18, no. 2, pp. 137–148, 2008.

[9] D. A. R. Chaves, H. A. Pereira, C. J. A. Bastos-Filho, and J. F. Martins-Filho, "SIMTON: A Simulator for Transparent Optical Networks," *Journal of Communication and Information Systems*, vol. 25, no. 1, 2010. [Online]. Available: http://iecom.dee.ufcg.edu.br/ jcis/