Traffic Grooming and Power Level Tuning for Physical Impairment Constrained Routing

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***Abstract*—In both, metropolitan optical networks (MON) and long haul optical networks (LHON) the signal quality is often influenced by the physical impairments, therefore proper impairment constrained routing decisions are needed.**

In this paper we propose two new approaches that jointly perform, on the one hand, routing and wavelength assignment (RWA) and, on the other hand, either tuning the signal power of certain Wavelength Division Multiplexed (WDM) channels or grooming the traffic of some WDM channels in nodes that are grooming capable.

We evaluate the proposed optimization methods for both, single and multilayer networks. In the first case we assume that no signal regeneration is allowed along the path, only re-amplification, while in the more complex two-layer case we assume grooming in the electronic layer that implicitly performs 3R signal regeneration and wavelength conversion as well.

***Index Terms*—Physical Impairment, Routing, Grooming, Power Level, Optimisation**

I. Introduction

THE idea to completely separate services from the transport appears for long time in numerous recommendations and papers. Similarly, when considering the services of optical networks it is expected that the signal is regenerated in the optical layer and there is no need to consider it at all while routing or configuring the connections. However, while the all-optical signal re-amplification has been solved by the fiber amplifiers (e.g., EDFA), there is still no commercially available solution for all-optical 3R regeneration, including re-shaping and re-timing of pulses impaired by the physical effects during the transmission along the optical fibers and nodes.

Therefore, in current, particularly metro and core networks the physical impairments are to be considered. One of the first papers dealing with the effects of transmission impairments onto the routing was [1] followed by many others, including [2], [3] and [4]. Recently a new European project has been started on this topic [5].

In this paper we propose solutions to moderate the limiting effect of physical/transmission impairments

- either by tuning the power level of certain signals (Section III),
- or by performing electronic signal re-generation via O/E/O conversion while the signal quality is still sufficient to achieve low bit error rates (BER) (Section II),

both combined and used jointly with taking proper routing decisions.

II. Joint Traffic Grooming and Routing for Resolving Physical Impairments

First, let us illustrate the problem. Figure 1 shows a part of a network, where three demands were already routed from s1, s2 and s3 to d1, d2 and d3 respectively, all using the fiber between nodes a and b. When we want to route a fourth demand between nodes s4 and d4, the shortest path will lead through the same link a-b.

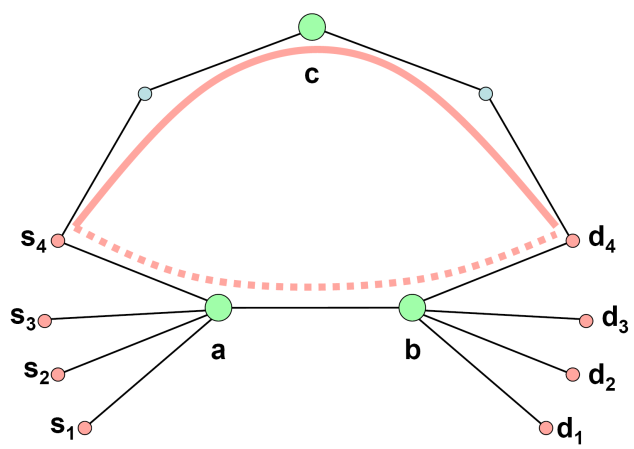

Figure 1: Illustration of the two PICR (Physical Impairment Constrained Routing) problems considered.

Let us consider the following cases:

- Case 1: If the distance between s_4 and d_4 is short

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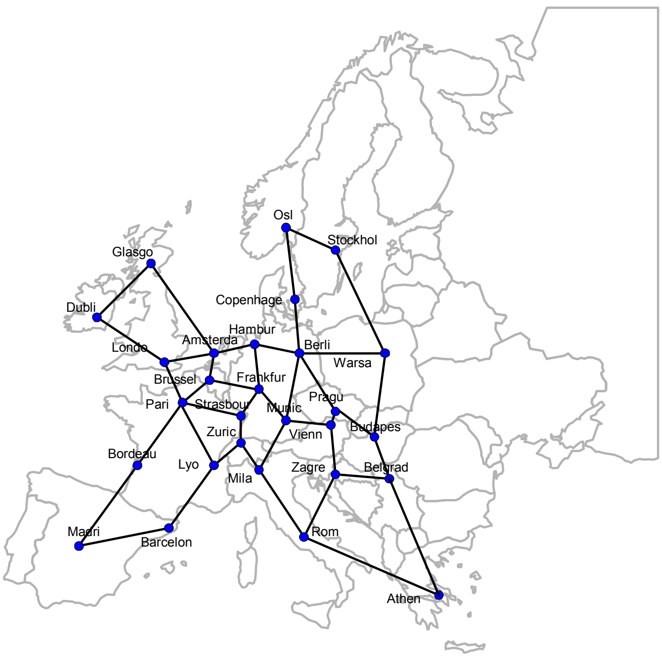
enough, the demand can be routed using a new wavelength-path and no 3R re-generation is needed.

- Case 2: The distance between s_4 and d_4 is too long therefore no direct wavelength-path can be set up. However, nodes *a* and/or *b* have traffic-grooming capability so that the signal can be re-generated.
- Case 3: If nodes *a* and *b* do not have grooming capability or all their grooming ports[1] are already used by other connections we will not be able to route the demand between s_4 and d_4 along the shorter path (marked as dotted). In this case a longer path (marked as solid) will be chosen, that has enough grooming capable nodes (and ports within these nodes) to maintain the good signal quality via implicit O/E/O conversion of grooming.
- Case 4: Otherwise, the demand can not be routed and is considered blocked.

The idea of the heuristic algorithm we used is explained in [6] for Case 2 and in [7] for Case 3. Its outline is as follows. We try to route each demand in the wavelength graph along its shortest path. We check which is the farthest node that can be reached in our Wavelength Graph model along this path without deteriorating the BER more than a given threshold value. Then we search for a new segment until the next node that can be reached, repeating until the destination node is reached (Case 2). If no grooming capability is present or it was already exhausted by other demands, we crank-back and try alternative segments (Case 3). If none succeeds the demand is considered blocked (as explained for Case 4).

We have carried out all the evaluations for the COST 266 reference network shown in Figure 2.



[1] Grooming ports, or simply ports are the O/E and E/O converter pairs between the optical switch / cross-connect that lead to the upper layer, i.e., to the electronic switching device.

Figure 2: The COST 266 Reference Network.

Figure 3 shows the achieved simulation results. We have evaluated the ratio of demands blocked to the ratio of the total of offered demands as we scale the network. Compared to the initial scale of 1 we have scaled down to 0.4 and up to 2.7, i.e. proportionally decreased and increased all the physical distances that has decreased and increased the transmission impairments, respectively. For network scale of 1 having 40, 80 or 1000 O/E/O add-and-drop ports between the optical and electronic grooming-capable layer yields roughly the same results. However, if we further decrease the number of ports to 20 or 10 the blocking will significantly increase for two reasons. First, the number of different wavelengths is not sufficient; therefore, to accommodate all the demands grooming is needed. Second, as the distances grow (i.e., the scale factor increases – horizontal axis), first the number of grooming actions will remain the same, however, their position will start to change, then after a while the number of grooming actions will be dominated by physical impairments, not by the traffic conditions anymore. It can be seen, that the sections of the blocking characteristic around the scale factor of 1 become steeper as the number of ports decreases. This is caused only by the increased impact of impairments induced by increased distances.

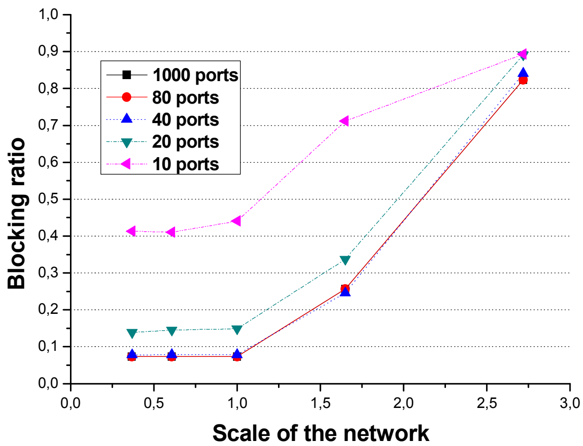


Figure 3: Dependence of the blocking on the network scale and grooming capacity (number of ports).

If we further decrease the scale factor of the network the blocking remains constant, i.e., the physical impairments are negligible – they do not influence the routing anymore. On the other hand if we further increase the scale factor, the distances will be so large, that hardly any demand can be routed without regenerations that rapidly exhausts all the grooming ports and causes extreme blocking.

III. Joint Power Level Tuning and Routing for Resolving Physical Impairments

Let us consider the second scenario, where we try to fight against impairments, by increasing the power level of certain signals. In this case the BER drops as the level of signal grows, but only until a certain threshold. When the total of channel powers in a certain link achieves a threshold, the transmission impairments will rapidly escalate due to non-linear effects!

To better explain the problem, let us consider Figure 1 again, however, this time assuming no grooming capability at all. Considering that link *a-b* is used by the largest number of demands it will have the highest total power level. If we want to improve the quality of the signal between any of the *s-d* node-pairs, we have to increase the power. However, as we increase the power of certain channels, the total power grows as well, that leads to risen nonlinear impairments. To avoid this problem we propose two solutions.

First, routing some of the demands to longer paths (solid instead of dashed path in Fig. 1) decreases the total power of critical links. This will need higher power for that wavelength-path, however if it does not use any critical link it is no problem.

Second, we propose using different power levels for different wavelength channels even within a single link. Although the optical equipment allows this uneven tuning, to our knowledge it has not been used so far. Nowadays in nearly all reconfigurable optical add-drop multiplexers (ROADM) the signal power can be tuned this way by the control plane via variable optical attenuators (VOA). The proposed methods can be used in existing WDM optical networks wherever the nodes support signal power tuning.

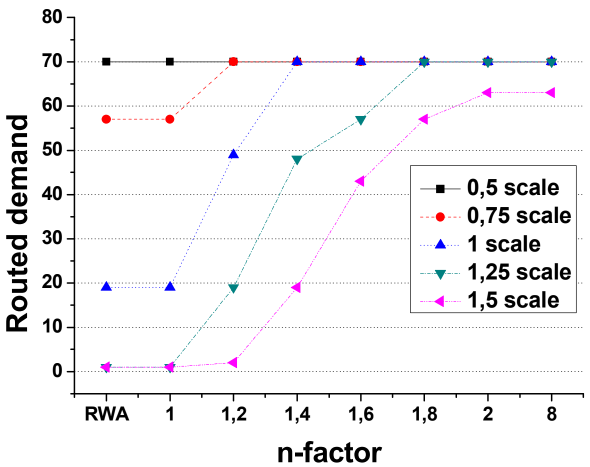


Figure 4: Maximum number of routed demands versus the n-factor for different scale parameters.

In [8] and [9] we propose a new method for finding the global optimum of the wavelength-path system configuration by simultaneously tuning the power levels for each wavelength path and routing these wavelength paths in order to minimize the effects of non-linear impairments while maintaining the sufficient signal level for required end-to-end signal quality in terms of BER. This method also minimizes the use of network resources within the constraints of end-to-end BER for each wavelength path.

These approaches are based on ILP (Integer Linear Programming) and on heuristics. If there exists a global optimum the ILP algorithm will find it, for any network topology, physical constraint and demand set. In [10] we generalize the results for two-layer grooming-capable networks as well.

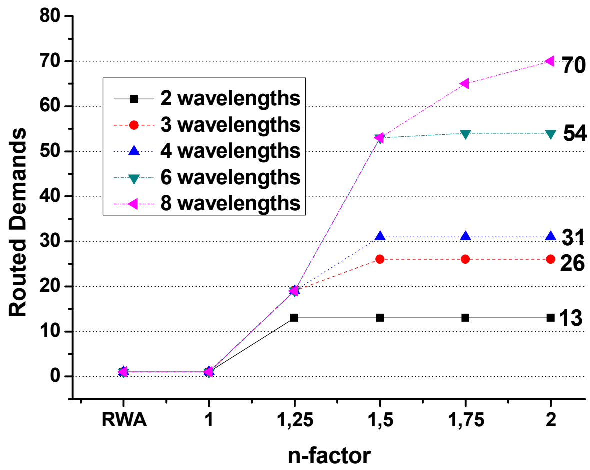


Figure 5: Maximum number of routed demands versus the n-factor for different number of wavelengths.

We have evaluated the proposed ILP based approach for the same network, shown in Figure 2. The results are presented in Figures 4 and 5. In both figures we evaluate the number of demands that can be simultaneously routed for certain n-factors, where n-factor is the ratio of the largest to the smallest power level (expressed in mW) of different wavelength channels within a single link. n=1 means, that all channels have the same value, while n=2 means, that a channel can have double power compared to another channel, while all the remaining channels have power in-between.

Figure 4 shows, that as we allow more and more diverse power levels, the amount of demands that can be routed grows significantly, e.g., from 18 to 70 for scale factor 1 while the n-factor grows from 1 to 1.4. This shows the great performance of allowing this minor difference in power levels! If we consider the scale factors, it can be seen that for value of 0.5 where physical impairments do not impact the number of routed demands at all, there is no difference – no need to use different power levels. However, for scale factors larger than 1, where the physical impairments become significant allowing different power levels results a tremendous growth in the number of routed demands. The first value on the horizontal axis marked as RWA is the reference method, where all the power levels are exactly the same.

Figure 5 shows the dependence of the number of routed demands on the n-factor as the number of wavelength channels is increased in the links of the WDM network. It can be seen that as the number of wavelengths grows, the proposed approach of allowing different power levels has an incredible positive impact: Instead of a single demand, up to 70 demands can be routed in a system with 8 wavelengths as the n-factor grows from 1 to 2!

IV. Conclusion

Here we have proposed two scenarios for Physical Impairment Constrained Routing (PICR). First, using the grooming capability present in certain nodes of the network to perform O/E/O signal regeneration. Second, to tune the signal power of certain wavelength-paths to different levels depending on the destination of that wavelength path, as well as on the current power budget of the links along that path. Both schemes were used simultaneously with routing over optical C/D WDM networks. Our simulations have shown that using the proposed schemes the ratio of demands routed can be significantly increased when comparing to the cases without the proposed schemes presented in Sections II and III.

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