

# Considering Transmission Impairments in RWA Problem: Greedy and Metaheuristic solutions

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**Abstract:** We face the RWA problem considering physical impairments. After proposing a simple, fast but accurate model for the physical layer that considers dynamic impairments, we devise both greedy and metaheuristic algorithms to solve RWA problems.

## Introduction

Wavelength Routed (WR) networks are considered the best candidate for the short-term implementation of a high-capacity IP infrastructure, since they permit the exploitation of the huge fiber bandwidth, but do not require complex processing functionalities in the optical domain.

In WR networks, remote high-capacity (electronic) routers are connected through IP-tunnels. IP tunnels are implemented by optical pipes called *lightpaths* that may extend over several physical links. Lightpaths can either be semi-permanent [1], or be allocated in on-demand fashion [2]. In the first case a static topology is seen at the IP layer. In this paper, we consider a transparent optical network, in which lightpath requests are statically set-up. Static Routing Wavelength Assignment (RWA) is an optimization problem and our objective is to maximize system performance in terms of OSNR. When solving the RWA problem, we take into account the impairments imposed by the physical layer. In particular, we consider the effect of *nonlinearities* which arise when considering wavelengths allocation on optical fibers.

## Model of physical layer

In order to analyze the evolution of the signals through a transparent optical network based on the Wavelength Division Multiplexing (WDM) technique, the wave equation for the fiber optic propagation should be solved for every optical link, together with mathematical models of optical components. Due to the nonlinear nature of the problem, and to the absence of analytical solutions, a rigorous analysis could need hundreds of hours of CPU time. Hence, it is not possible to setup a RWA analysis that may require to evaluate the network performance for possible millions different network configurations, i.e., millions extremely time consuming simulations of the physical layer. In order to overcome the computational limits many approximated solutions have been presented in the technical literature [3], [4],[5]. Our approach however adopts simpler physical models, and more complex optimization algorithms. In particular, given that we want to use metaheuristic approach, a simple and fast OSNR evaluation is mandatory.

To define the goodness of a lightpath we estimate the related *Optical Signal-to-Noise Ratio* (OSNR) and its penalties due to linear and nonlinear propagation effects, defining for each lightpath:

$$OSNR = OSNR_{ASE} - OSNR_{pen,lin} - OSNR_{pen,nl} \text{ [dB]}$$

where  $OSNR_{ASE}$  is the value deriving from the noise accumulation, whereas  $OSNR_{pen,lin}$  and  $OSNR_{pen,nl}$  are penalties deriving from linear and non-linear propagation impairments, respectively. Therefore, the *Bit Error Rate* (BER) for the considered lightpath can be directly related to the OSNR [5]. Main approximation is given by the separation of effects. The calculation of  $OSNR_{ASE}$  and  $OSNR_{pen,lin}$  are derived using models known from the literature [6] and we focus our attention on  $OSNR_{pen,nl}$ . It is important to remark that  $OSNR_{pen,nl}$  depends on the number of wavelengths turned on in the fiber, therefore it depends on dynamic network configuration. In particular we consider XPM effects and in order to assess the signal degradation due to XPM, we performed a series of Monte-Carlo simulations on a defined test-link using the optical system simulator OptSim. From the results of these simulations we deduced an approximate empirical function giving the noise standard deviation  $\sigma_{XPM}$  of a channel at the end of the fiber:

$$\sigma_{XPM} = \frac{P_{TX} L_{eff} \gamma K \log(N_w)}{\Delta f_{min}}$$

where  $P_{TX}$  is the channels power,  $L_{eff}$  is the effective length of the link,  $\Delta f$  is the channel spacing between channels,  $N_w$  is the number of the established channels in the fiber,  $\gamma$  is the fiber nonlinear coefficient and  $d_{min}$  is the minimum

distance between the wavelength under observation and the used wavelengths.  $d_{min}$  assumes values in  $[1, W-1]$ , where  $W$  is the number of wavelengths in the fiber. Finally  $K$  is a constant used to fit the values given by XPM function with values obtained from OptSim simulator. This function takes into account that interference due to XPM is a monotone increasing function with the number of wavelengths actually in use on the fiber and with power per channel, whereas it decreases with the increasing channel spacing due to walk-off effect [7]. XPM penalty varies with the number of wavelengths in use for each fiber and with their spectral assignments. In the evaluation of the XPM impairments our model always considers the worst case situation in terms of channel spacing, i.e., given the number of channel turned on a fiber span, the function  $\sigma_{XPM}$  considers all the channels uniformly spaced with the minimum channel spacing.

### Application of RWA algorithms

Given a physical topology and a list of lightpath requests, our goal is to find an RWA solution that maximize the minimum OSNR among the lightpaths in the request list. Therefore we consider the minimum OSNR in the network as the objective function of our optimization approach. To face the RWA problem, we consider both greedy and metaheuristic algorithms. Being the RWA problem a NP-complete problem [8], it is not possible to find the optimal solution. While greedy algorithms seek for a *single admissible* solution, metaheuristic algorithms aim at exploring the space of admissible solutions following a smart path, testing usually millions of admissible solutions.

As greedy algorithms, we selected both the *First Fit-Minimum Hop* (FF-MH) [8] and the *Best-Optical Signal Noise Ratio* (B-OSNR) [9]. The greedy solution is obtained by considering each request according to its position in the lightpath list. The FF-MH algorithm selects i) the minimum hop path between the source and destination node, and ii) the first available wavelength on all fibers along the path. Being a traditional algorithms, the FF-MH fails to consider physical impairments on a given path/wavelength. Therefore, we propose another greedy algorithm, B-OSNR, which jointly assign to a given request a path and a corresponding wavelength: for a given request, the path/wavelength solution which presents the maximum OSNR will be selected. To limit the complexity of the algorithm, we considered only the first 50 minimum-hop paths (if available) between each source and destination. Physical performance are updated at each iteration, i.e., after that a lightpath request has been considered.

Considering metaheuristic algorithms, we implemented both Simulated Annealing (SA) and Taboo Search (TS) local search algorithms [10]. We describe only the SA approach, given that it proved to offer the best performance. SA is a stochastic iterative search strategy originated in the annealing processes found in thermodynamics. The value of the objective function that we want to optimize is analogous to the energy in a thermodynamic system. At high temperatures, the algorithm has more random behavior, since worsening solutions with higher energy are more likely to be accepted avoiding to trap into a local maximum. Then, temperature parameter is progressively lowered until the system reach a state of low energy, in which the likelihood of accepting a worsening solution is much lower and the search reduces to a local search. If we consider our objective, we note that states of high energy correspond to low values of our objective function and states of low energy correspond to high values of our objective function. A general SA procedure consists of the following steps:

- Step 1: Choose an initial solution  $x_0 \in X$ , being  $X$  the space of valid solutions.  
Set  $x_c = x_0$ , where  $x_c$  denotes the current solution.
- Step 2: Generate a random neighbor solution  $x' = M(x_c)$   
Compute the difference  $\Delta E = E(x_c) - E(x')$ , where  $E(x)$  denotes the energy of the solution  $x$   
If  $\Delta E \geq 0$ , then  
    accept the solution  $x_c = x'$   
Else  
    compute the probability  $p = \exp(-\Delta E / T_n)$ , being  $T_n$  the temperature at  $n$ -th step  
    If  $r < p$ , then accept the solution  $x_c = x'$ , being  $r$  a random value in  $[0,1]$
- Step 3: If a stopping condition is met, then stop  
Else go to Step 2.

$M(x_c)$  is called “move” and it is the procedure to generate a valid neighbor from the current solution  $x_c$ . In our implementation, the “neighbor” is generated by swapping two requests at random in the lightpath list, and re-applying the B-OSNR assignment to the involved requests. Because of the dependence of the RWA solution on the position of the lightpaths in the list, the proposed “move” at each iteration perturbs the requests order for finding new RWA solutions. Moreover, a new SA procedure restarts the local search in a previously unexplored region if, after 3millions of iterations, no improving solution has been found, i.e., by randomly shuffling the lightpath request list. The algorithm ends after 30millions of iterations (about 250s on a Pentium IV Linux box).

## Simulation results

We considered as physical topology the Italian Optical Network which was derived from a possible evolution of the *Telecom Italia Spa* network which includes 32 nodes. We assumed that the network is cabled using *Non-Zero Dispersion Shifted fiber*. In order to recover fiber losses, we considered to use EDFAs spaced  $L_{span}$  km=40km that perfectly recover the loss introduced by the preceding fiber span. We assume to use dispersion compensation techniques and that the *PMD* effect is negligible at the supposed bit-rate of 10 Gbit/s. The maximum number supported wavelengths is set to 30. 250 lightpath requests are generated at random by uniformly selecting the source and destination nodes.

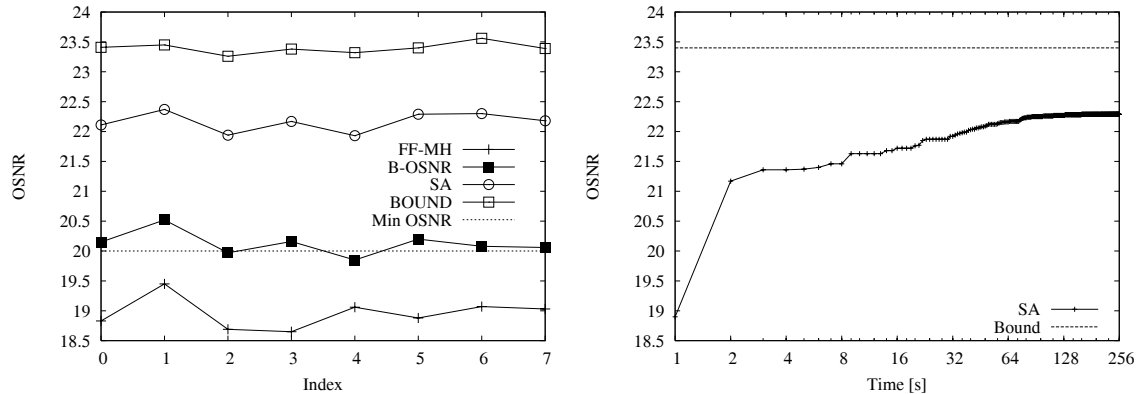


Fig. 1: Minimum OSNR obtained with different optimization algorithms on the left, and evolution of the SA algorithm during time on the right.

Left plot of Fig. 1 shows the result obtained by the different algorithms. Eight different logical topologies are considered as input to give the intuition about the sensitivity to the request list. For each input set, the RWA is solved using the above described algorithms. An upper bound is also reported to compare results to a possible optimal solution, and the minimum required OSNR is reported and set to 20dB, i.e.,  $BER < 10^{-12}$ . As it can be observed, the FF-MH gives the worst results, given that it does not consider at all the OSNR impairments. The B-OSNR on the contrary improves the solution of about 1dB, but does not meet the min OSNR requirement in all scenarios. On the contrary, the SA shows the benefit of a metaheuristic approach. Indeed more than 2 dB are gained compared to the B-OSNR greedy solution, always meeting the min OSNR constraint. To gauge the evolution during the optimization phase, right plot of Figure 1 plots the best OSNR value found during the SA optimization process. Time is reported on the x-axis using log scale. Notice the large improvement obtained by the optimization at the beginning, opening also the possibility to use the SA algorithm in scenarios in which short time can be devoted to solve the RWA problem.

## Conclusions

We considered the routing and wavelength assignment problem under transmission impairments. Both static effects and nonlinearities are considered during the RWA solution, and the XPM is explicitly modeled. While greedy heuristics can be designed to take into account the OSNR impairments, metaheuristic approaches like the Simulated Annealing show large gains, improving the minimum OSNR faced by lightpaths by up to 3 dB.

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