Mutual Impact of Physical Impairments and Grooming in Multilayer Networks

Szilárd Zsigmond[1], Gábor Németh[1], Tibor Cinkler[1],

[1] Budapest University of Technology and Economics,
Department of Telecommunications and Media Informatics
2nd Magyar Tudósok Krt., Budapest, H-1117
{zsigmond, nemeth, cinkler}@tmit.bme.hu

Abstract. In both, metropolitan optical networks (MON) and long haul optical networks (LHON) the signal quality is often influenced by the physical impairments, therefore a proper impairment based routing decision is needed. In the absence of all-optical 3R regenerators, the quality of transmission has a strong impact on the feasibility of all-optical transmission. It is assumed that signal regeneration can be done only in electrical layer. Once the signal is in electrical layer there are some features supported e.g. the traffic grooming. We show that by taking into account both, the physical impairments characterized by the Q-factor, as we propose, and the features of the electrical layer, will have a strong impact onto the routing that is based on impairment constraints.

Keywords: ASE, PMD, ICBR, Grooming, OSNR, Q-factor

1 Introduction

The tremendous growth in broadband communication services, brought for the phenomenal expansion of the internet, has triggered an unprecedented demand for bandwidth in telecommunication networks. Wavelength division multiplexing (WDM) has been introduced to increase the transmission capacity of existing optical links. Multi-wavelength technology appeared as the solution for the bandwidth hungry applications. WDM has been introduced to increase the transmission capacity of existing optical links. It has been soon recognized that the switching decision can be made according to the incoming wavelength without any processing of the data stream. In single hop WDM based All Optical Networks (AON) a wavelength is assigned to a connection in such a way that each connection wavelength is handled in the optical domain without any electrical conversion during the transmission [1], [2]. Routing and Wavelength Assignment (RWA) takes a central role in the control and management of an optical network. Many excellent papers deal with design, configuration and optimization of WDM networks. See e.g. [3]-[5]. The majority of these RWA algorithms assume that once the path and wavelengths have been identified, connection establishment is feasible. This is true when we consider that in each node the signal is regenerated but may not be true in transparent networks, where the signal quality degrades as it is transmitted through optical fiber and nodes.

Impairment constraint-based routing (ICBR) may be used in transparent networks as a tool for performance engineering with the goal of choosing feasible paths while obtaining the optimal routes regarding the RWA problem. Many excellent papers have been written about constraint based routing which obeys physical effects [6-9].

There is no doubt, that the near future info-communications will be based on optical networks. In general for networks of practical size, the number of available wavelengths is lower by a few orders of magnitude than the number of connections to be established. The only solution here is to join some of the connections to fit into the available wavelength-links. This is referred to as traffic grooming. The main idea of our optimization was that in optical layer we do not make signal regeneration. We assume that in the optical layer, there is no signal regeneration, and the noise and signal distortion accumulate along a lightpath. Actually, re-amplification, re-shaping, and re-timing, which are collectively known as 3R regeneration, are necessary to overcome these impairments. Although, 3R optical regeneration has been demonstrated in laboratories, only electrical 3R regeneration is economically viable in current networks.

We have already mentioned that in the electric layer it is possible to do traffic grooming. If we investigate the physical limitations in the optical domain, and take them into consideration, we will have to include new optical-electrical-optical conversion just to ensure the quality prescriptions. These new optical-electrical-optical conversions will have influence onto the RWA process.

The rest of the paper is organized as follows. Section 2 describes the investigation of the physical layer impairments. In Section 3 we describe the routing and wavelength assignment process. In Section 4 the results are presented and finally in Section 5 we conclude our work.

2 Modeling the Physical Layer Impairments

The signal quality of a connection is characterized by Bit Error Ratio (BER). Experimental characterization of such systems is not easy since the direct measurement of BER takes considerable time. Another way of estimating the BER is to degrade the system performance by moving the receiver decision threshold value, as proposed in [10]. This technique has the additional advantage of giving an easy way of estimating the signal quality (Q) of the system, which can be more easily modeled than the BER. [11] explains well and gives a definition to it. The Q-factor is the signal-to-noise ratio of the decision circuit in voltage or current units, and can be expressed by:

$$Q = \frac{\langle I_1 \rangle - \langle I_0 \rangle}{\sigma_1 + \sigma_0} \quad (1)$$

where: $I_{1,0}$, is the mean value of the marks/spaces voltages or currents, and $\sigma_{1,0}$ is the standard deviation

In our model we consider a chain of amplifiers and optical cross-connects (OXC). The calculation of the Q is based on [12] where fully transparent optical cross connection architecture is presented. In this study the OXC architecture is based on wavelength selective architecture, as can be seen in Figure 1. The switching is done for each wavelength by an (N+1)x(N+1) switch that is included between the demultiplexer and the multiplexer.

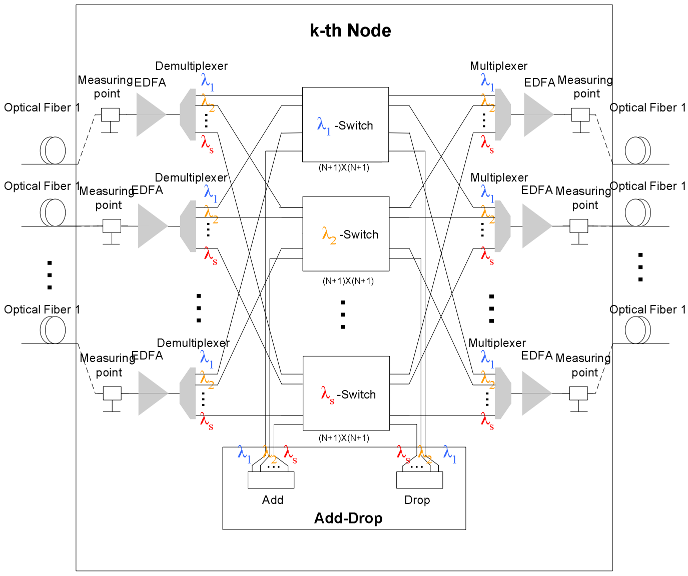

Figure 1: Architecture of an OXC

In this approach the noise, power and distribution for ones and zeros are calculated recursively. Assuming we know the ASE and crosstalk parameters at node k-1 and the parameters of node k, then we can calculate the ASE and crosstalk parameters at node k. In this approach the crosstalk is introduced only in the OXC nodes and ASE is introduced by the erbium-doped fiber amplifiers (EDFA), which the signal passes through. We assume that in every 80 km there is an inline amplifier.

The impact of PMD onto the signal quality can be calculated based on [13], where the PMD-induced degradation is assessed by an eye-opening penalty (EOP) along the lines. This EOP is subsequently translated to a Q-factor penalty. [14]

The main physical parameters of the network can be seen in Table1.

Nf	4,8 dB	Noise figure of the EDFA
X_{sw}	40dB	Crosstalk of the switch
D_{pmd}	0,1ps/nm*km	PMD coefficient of the fiber
Alpha	0.2 dB/km	Fiber Attenuation
L_{tap}	1dB	Attenuation of the measuring point
L_{mx}	4dB	Attenuation of the multiplexer
L_{dmx}	4dB	Attenuation of the demultiplexer
L_{sw}	8dB	Attenuation of the switch
OP	10^{-3}	Outage probability
P_{out}	8dBm	Total Output of an EDFA

Table 1: The main physical parameters of the network

3 The Routing Model

The routing algorithm is a highly complex algorithm which can handle optical nodes, electrical nodes and optical nodes with electrical regenerations. We consider two layer architecture, an electrical layer and an optical layer. The electrical layer supports some features such as traffic grooming and λ-conversion. The routing is realized by a shortest path algorithm. Each link and node has its own cost. In this way we can choose the lowest cost path by implementing Dijkstra's algorithm. This algorithm can route demands dynamically. The input of the optimization is the network topology and the demands. The output of the algorithm is the set of optimal routes and statistical data on the blocking in the network. The routing parameters contain information about the blocking ratio and the reason why the route has been blocked. A route can be blocked due to the RWA problem, or because of the physical impairments. A route is blocked due to RWA problem if there is not enough resource to route the demand between the source and destination node. This happens when all the wavelengths are used or in case of grooming there is not enough free capacity to groom the demand We consider a route blocked due to physical impairments if Q value of the route is lower than 3.5 which is still acceptable if using coherent detection schemes.

3.1 Routing Algorithm

The setup of the algorithm can be split in two main parts. The first one is the routing part and the second one is the calculation of physical impairments (CPI), which can be switched on or off, (Figure 2). The communications between these two parts are as follow: The routing algorithm chose an optimal route, between the source and destination node and if the CPI is switched on, it sends the description of the route to CPI. The description of the route contains the lengths of the optical fibers between the nodes. The CPI calculates the signal quality and if it is adequate it sends a message back to the routing part, that the connection can be established. If the signal quality is not adequate the CPI determines the maximum reachable node (MRN) along the path and sends this information back to the routing model. The routing model establishes the connection between the source and the MRN, than chooses another route between the MRN and the destination node. If the MRN is the source node e.g. there is no possible connection due to the physical layer, the route is blocked.

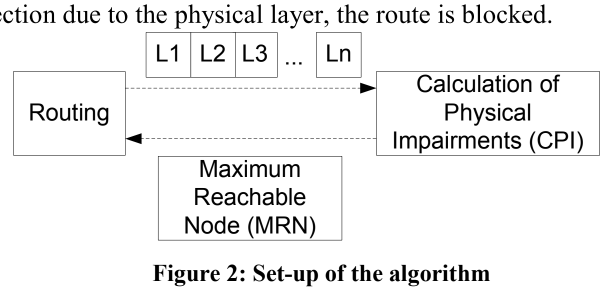

Figure 2: Set-up of the algorithm

To perform the effects of grooming onto the ICBR we made fore *simulation* types.

- The first one when there is no grooming in the RWA and the physical effects are negligible
- The second one when there is *grooming* and the physical effects are negligible
- The third one when there is no grooming in the RWA and we take into consideration the *physical effects*
- The fourth one when there is *grooming* and the *physical effects* are taken into consideration

As it was mentioned before the routing is done by a shortest path algorithm, when each link has its own cost. By using different cost values for the links of the network we can optimize an RWA oriented, or a physical impairments oriented routing. For this purpose we use four *metrics*.

- The first one where the cost of each link is the same. Will be referred as *hop routing*.
- The second one when the cost of each link is equal to the length of the link. Will be referred as *length routing*.
- The third one when the cost of the link is equal to the $1/Q$ where the Q is the Q-factor of the link
- The fourth one when the cost of the link is equal to the $1/Q^2$ where the Q is the Q-factor of the link

In the case of the third and of the fourth metrics we calculate the Q-factor of each link as a point-to-point connection between the two end nodes of the link. The Q-factor based routings are not obviously the best routings for the point of view of the physical layer. This is due to the nonlinear behavior of the Q-factor. If we have two lightpats, each lightpath has its representative Q, for example Q_1 and Q_2. Consider a route which contains these two lightpats in chain. The overall Q can not be calculated from these two Q-factors, if we take both the PMD and ASE effects into calculation. The only assumption which we can make, is that, if Q_1 and Q_2 have a high values than the overall Q will be high as well.

The exact flow of the algorithm can be seen in Figure 3.

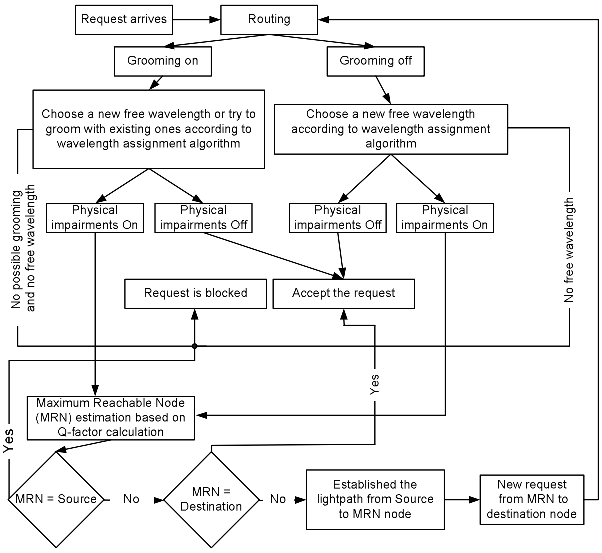

Figure 3. Flow chart of the algorithm

3.2 Network and traffic generation

The used network scenario is one of the COST266 [15] reference networks, Figure 4. Each link contains 24 wavelengths. The used bit rate is 10Gbit/s. The generation of the demands is based on the traffic matrices for year 2006 of the COST266 European Reference Network. More than 9000 demands were generated and routed in each simulation. The arrival of the demands occurred according to a Poisson process with the intensity of 0.005.

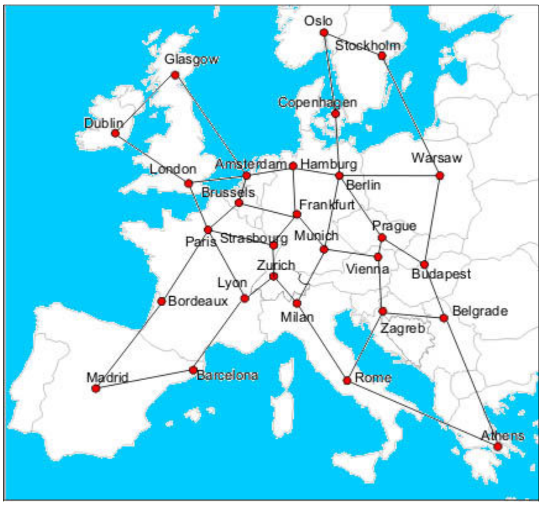

Figure 4: Used network scenario

4 Simulation Results

We compared the four metrics used for representing the cost values of the links, in Figure 5-6. In Figure 5 the calculation of the physical impairments was switched off and the grooming capability was switched on, and in figure 6 both modules were switched on. In the X axis the scale of the network can be seen. The meaning of it is that we changed the used network link lengths by multiplying the original lengths with the scale parameter. This resulted in increase of impairments. On the Y axis the blocking ratio is plotted. In Figure 5 it is to be seen that the best metric from the point of view of the blocking ratio is the hop-metric followed by 1/Q and $1/Q^2$ metrics while length metric yields the worst results. We expected that in case when the physical impairments are switched off the scale of the network has no influence onto the blocking ratio. This is true when the grooming is switched off. In case of grooming there are several routing decisions which have the same ratio so it is done randomly. These random decisions lead to the non-deterministic behavior.

In figure 6 when the physical effects are taken into consideration the differences between the four metrics decrease. To understand this behavior we investigated the blocking ratio dependency on to the physical effects, see figure 7. In the X axis the network scale and in the Y axis the blocking ratio due to physical effects is plotted. This blocking ratio contains only the blockings due to physical effects without rerouting. This means that the routing module chooses an optimal lightpath and the CPI module calculates its Q-factor. If the Q is lower than 3,5 then the request is blocked. This is a more simplified scenario than the one presented in Section 3. In Figure 7 it is to be seen that the characteristics of the curves are what we expected. In case of low network scales, where the lengths of the links are very small, where the physical effects have no influence, the blocking ratio is very low. While increasing the link lengths, we increase the influence of the physical effects, the blocking ratio is increasing. We compared the four metrics from the point of view of blocking ratio due to physical impairments i.e. grooming and rerouting capabilities were not used at all. Length routing has the best performance while hop routing has the worst. Between these two are the Q-based routings. Of course it is possible to find a metric which is the function of Q, f(Q), that gives better results than the length based metric, however this is not the scope of this paper.

Returning to Figure 6 the blocking ratio subsidence between the four metrics is due to the constraints on the physical effects. In the aspect of physical effects the best metric is the length followed by the $1/Q^2$, and the 1/Q while the worst is the hop metric. From the point of view of RWA the order of these four metrics is reverse. Taking into account both the physical effects and the RWA problem, as we did, will leads to the behavior.

The other interesting property is that while increasing the scale of the network the blocking ratio decreases. This is due to the fact that increasing the lengths of the network increases the influence of the physical effects. The effect of this influence is that we have to do more optical-electrical-optical regenerations (OEO). If there are more points where the signal goes to the electrical layer, and we are capable to groom in these nodes, the network will be more optimally used. This leads to decreased blocking ratio.

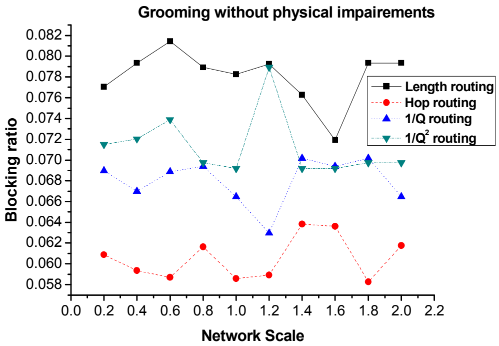

Figure 5: Blocking ratio dependency from the scale of the network in case of grooming without physical effects

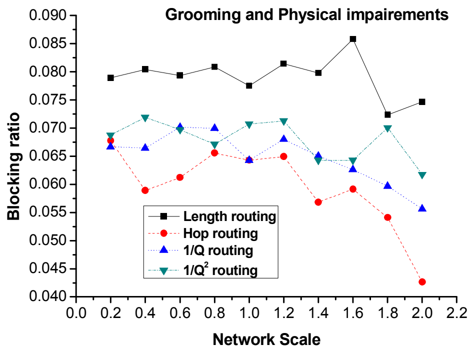

Figure 6: Blocking ratio dependency from the scale of the network in case of grooming and physical effects

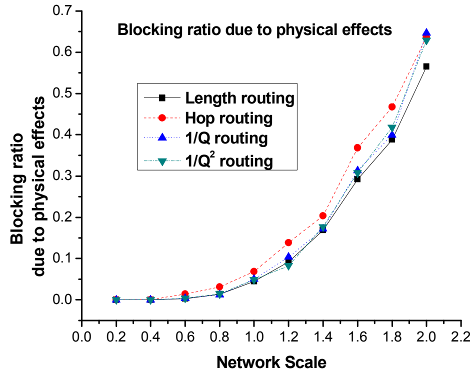

Figure 7: The dependence of the blocking ratio on physical effects from the as the network scales.

In Figure 8 we plotted the blocking ratio dependency on the scale of the network for the four routing scenarios using the length routing metric. The characteristics of the curves were the same for each metric. As it was expected there is a huge difference in the blocking ratio when the grooming capability is switched on or off. The other interesting property is that in case when the grooming is switched off and the physical impairments constraints are taken into consideration while increasing the scale of the network the blocking ratio is increasing. This is because increasing the lengths of the network the physical effects become dominating so we have to do more often OEO regeneration which increase the overall load of the network. In case when the nodes are capable to groom this trend of blocking growth can not be observed. As we mentioned before, see Figure 6, the blocking ratio is even decreasing while increasing the scale of the network.

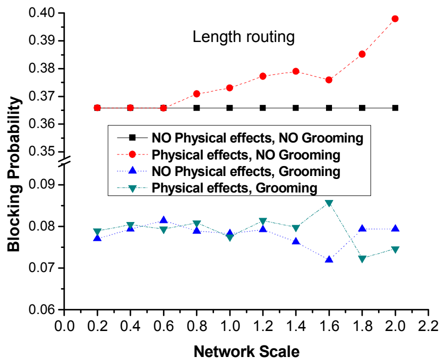

Figure 8: The dependency of the blocking ratio from the scale of the network for the four routing scenarios using length routing metric.

5 Conclusion

In this paper we presented a simple way of modeling the physical effects of the network. We demonstrated that the physical limitation must be taken into account while routing decisions are taken. While the signals pass through the network their quality deteriorates. Considering that signal regeneration can be done only in electrical layer, since all optical 3R regeneration is not commercially available, there are some nodes where the signal is converted to electrical layer. Once the signal is in the electrical layer except regeneration there are some additional features that can be performed such as wavelength conversion or grooming. If all this effects are taken into account the results express that physical limitations have serious impact onto routing and wavelength assignment strategies.

We show that by increasing the scale of the network the influence of physical impairments grows. The effect of this influence is that we have to do more optical-electrical-optical regenerations (OEO). If there are more points where the signal is in electrical layer and we are capable to groom in these nodes the blocking ratio is even decreasing while increasing the scale of the network.

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