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Abstract:

This document is the second deliverable of the WP26 "Topical Project on Alternatives for multi-layer networking with cross-layer optimization". This report gives an overview of the WP26 activities during the first ten months of the project and the plans for the second year. During the first year of BONE project, five joint activities were running and active and new joint activities are compiled and distributed among all partners in order to initiate new joint activities during the next year of this work package. Six conference/workshop papers and two journal papers are the dissemination outcome of these joint activities.

Keyword list:

Cross-layer optimization, optical network planning and design, Physical impairment aware routing and wavelengths assignment, Multi-layer algorithm using Bayesian theory, Traffic grooming, Traffic engineering in integrated control plane models

Disclaimer

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2. Executive Summary

This document is the second deliverable of the work package “Typical Project on Alternatives for multi-layer networking with cross-layer optimization”. The main objectives of this deliverable are to provide the results and outcomes of the performed activities of the running joint activities and also the activities that are planned for the coming year. During the first year of BONE project, five joint activities were running and active and new joint activities are compiled and distributed among all partners in order to initiate new joint activities during the next year of this work package. The current joint activities are: Multi-layer algorithm using Bayesian decision theory, RWA (routing and wavelength assignment) and regenerator placement (RP) in semi-transparent networks, Algorithms for multi-layer optimization with ICBR constraints, ICBR algorithm taking into account traffic grooming, Traffic Engineering in Integrated and Interconnected Control Plane Models in the Presence of Physical Impairments. Six conference/workshop papers and two journal papers are the dissemination outcome of these joint activities. Four mobility actions are also performed during the reporting period.

3. Introduction

This work package, identified as a Topical Project (TP) on Alternatives for multi-layer networking with cross-layer optimization, combines a large number of partners currently working on various research fields interoperable to each other. The long term focus is to define the possible future solutions for converged IP/ Ethernet over optical layer and create a common platform for the protocol and algorithm designs that will result in optimised solutions. Future developments in this area could benefit from this as all will have a common approach and work on a well defined target. This will allow optimum converged solutions to be proposed and developed in a more commonly adopted fashion. Therefore, multi-layer as well as multi-domain issues can be handled both faster and in a more efficient way within the European networks.

3.1.1 TP Objectives

This TP targets the following focus points:

1) Multi-layer approaches (architectures, protocols and network characteristics) for future Internet Protocol (or Ethernet) convergence over optical network solutions.
2) Cross-layer optimization approaches that take into consideration the physical layer, transport/data link layer and network layer characteristics.

The specific objectives for each domain are as follows:

Objectives of multi-layer approaches:

- Identification of various solutions for converged IP over optical networks and the networking issues related to each solution.
- Identification of the networking parameters that must be taken into consideration when examining the performance of multi-layer networks.
- Examination of modelling challenges related to the multi-layer networking simulations.
- Development of performance evaluation tools for various multi-layer network solutions.

Objectives of cross-layer optimization:

- Identification of the lower layer parameters (e.g. physical impairments, resources availability etc) that can be offered and monitoring methods to collect and disseminate this information to the network.
- Identification of higher layer parameters (e.g. QoS requirements, traffic demands etc.) and ways that these can be included in the development of fast reconfiguration algorithms
- Development of cross-layer optimization schemes and routing/decision protocols.
- Performance evaluation and feasibility studies.

3.1.2 Deliverable goals

The main goal of this deliverable is to report the results and outcome of the performed activities within the framework of this TP and also to report the activities that are planned for the remaining time of this TP.

4. Participants

Table 1 (in alphabetic order of partner's short name) provides a list of participant in the joint activities of this WP.

Table 1: Participating partners in joint activities of WP26

Partner Number	Short Name
P19	AIT
P42	BILKENT
P24	BME
P08	COM
P09	CTTC
P01	IBBT
P37	IT
P29	POLIMI
P30	POLITO
P21	RACTI
P31	SSSUP
P10	TID
P02	TUW
P11	UAM
P47	UEssex
P13	UPC
P14	UPCT
P07	UST-IKR

5. Joint Activities

This chapter describes the joint activities that are running and active in this work package. The following table shows key information about these joint activities:

No.	JA Title	Contact Person	Participants	Mobility Action	Deadline
1	Multi-layer algorithm using Bayesian decision theory	Víctor López (UAM) victor.lopez@uam.es Juan Fernandez Palacios (TID) jpfp@tid.es	UAM, TID		M24
2	RWA (routing and wavelength assignment) and regenerator placement (RP) in semi-transparent networks.	Eva Marin (UPC) eva@ac.upc.edu	UPC, AIT, TUW, POLIMI, IT, UPCT	Yes	M24
3	Algorithms for multi-layer optimization with ICBR constraints.	Pablo Pavon Pablo.pavon@upct.es	UPCT, TID, AIT, RACTI, BME, UPC,CCTC,UAM, BILKENT,	Yes	M24
4	ICBR algorithm taking into account traffic grooming	Szilárd Zsigmond zsigmond@tmit.bme.hu	BME, AIT, IT	Yes	M24
5	Traffic Engineering in Integrated and Interconnected Control Plane Models in the Presence of Physical Impairments	Namik Sengezer namik@ee.bilkent.edu.tr	BILKENT, BME		M12

Table 2: Summary list of the planned joint activities

As it is mentioned in the above table, five joint activities with at least three mobility actions are planned for this work package. The duration of most of the joint activities covers the two years of the project.

5.1 Multi-layer algorithm using Bayesian decision theory

5.1.1 Motivation and objectives

Network operators have understood the importance of migrating their backbone networks to IP over WDM architectures. In such multi-layer networks, it is necessary to efficiently combine the resources available from both layers in order to provide enhanced Quality of Service (QoS) to end-users. Thanks to the improvement of the control plane in backbone networks (GMPLS and ASON), it is feasible to set lightpaths up and tear them down automatically.

This JA extends the earlier proposal of a multi-layer Bayesian decisor to a multi-hop scenario. The Bayesian decisor finds a compromise between Quality of Service provided by both the optical and electronic resources and their relative techno-economic costs. The mathematical formulation of such Bayesian decisor is reformulated for a multi-hop scenario, and its behavior is further analyzed for different configurations found in realistic scenarios.

5.1.2 Summary of results

When the switching nodes have multiple switching alternatives (electronic, optical fiber based, optical wavelength based, optical packet based etc.) an important question to answer is how to map the traffic flows on the switching layer. This activity proposes a solution to this question in a multi-layer capable router, which can route the incoming LSPs in end-to-end lightpaths or in hop-by-hop connections.

Next figure shows a generic multi-hop scenario where each router is serving N_j LSPs. Each router sends e_j LSPs to the next router using the hop-by-hop connecting and the remaining traffic ($N_j+e_{j-1}-e_j$) is sent using the optical layer establishing a direct light-path between the node j and the destination node. Let us remark that the last hop does not have to make any choice.

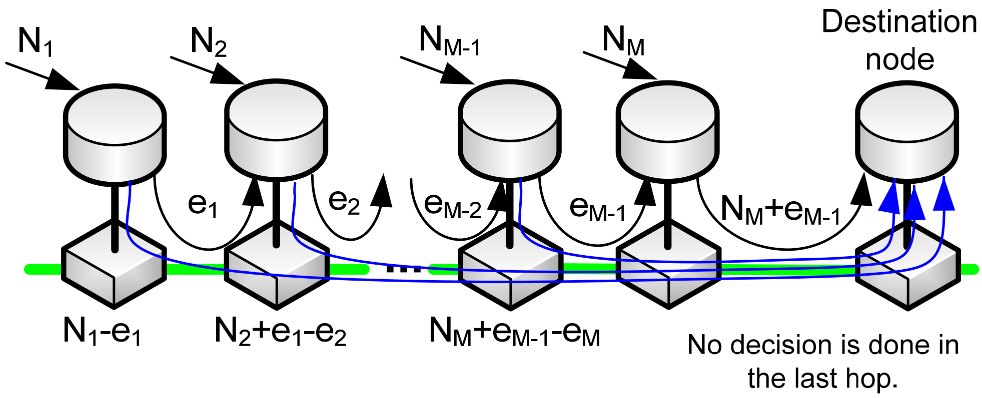


Figure 1: Multi-hop scenario definition

Network operator has a certain number of routers and cards deployed in their network. This IP equipment should be used while the network can provide the necessary QoS to the users. When the IP layer cannot absorb such demand, the incoming LSPs are sent using the optical layer. This proposal trades off two objectives, (1) provide an appropriate QoS definition for managing IP and optical switching; and (2) evaluate the techno-economic impact in the operator's network of using electronic and optical switching.

To carry out both objectives, we defined a risk function as follows:

$$R(\vec{e}, x_j^{e2e}) = K_c C_T(\vec{e}) - K_u \sum_{j=1}^{M} \mathbb{E}_x \left[U(x_j^{e2e}) \right], \quad x_j^{e2e} \geq 0$$

where ê is a vector decision with the number of LSPs sent in the hop-by-hop connections, C_T(ê) is the utilization cost, U(x) is the utility perceived by the user, x^{e2e}_j is the end-to-end delay from the node j to the destination node and K_c and K_u are normalization constants.

The utility functions, U(x), measure the QoS experienced (in terms of queuing delay) by the electronically-switched packets. Three utility functions are proposed:

- **Mean utility (U_{mean}):** computes the mean delay of the LSPs in the electronic domain.
- **Hard-real time utility (U_{step}):** evaluates the probability that the delay in the router queue is lower than a given Tmax threshold.
- **Elastic utility (U_{exp}):** assesses the gradual degradation of elastic services.

The utilization cost function quantifies the relative cost of optical switching with respect to electronic switching (R_{cost}). We have considered a linear cost approach that evaluates the ratio at which the optical cost increases with respect to the electronic cost. Besides the longest the light-path the cheaper is, in order to encourage the creation of longer lightpaths.

Let us evaluate the behavior of the algorithm in a three hops scenario (see next figure). When we increase the end-to-end traffic, the first node sends LSPs till it is saturated and a by-pass light-path is created from the source to the destination.

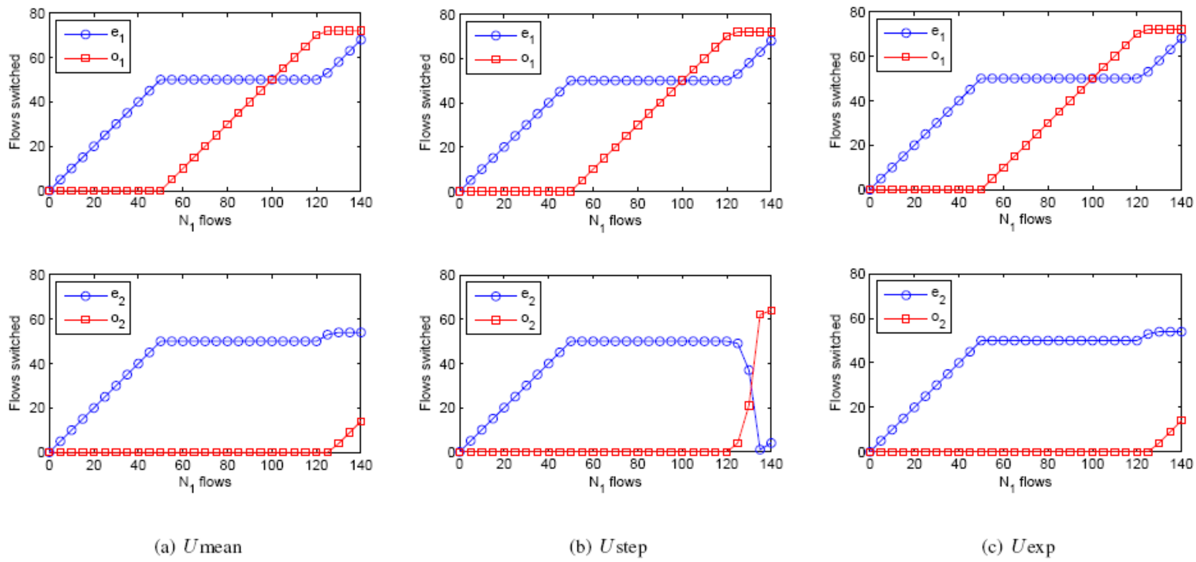


Figure 2: LSPs sent through the electronic and optical layers at nodes 1 and 2 when the load in the first node increases

We can see that using U_{step} when the amount of traffic saturates the first node and the light-path from the source to the destination all traffic is reverted from the IP layer in the second node and a second lightpath is created from the second node to the destination. This example shows how our algorithm is able to have different behavior depending on the application.

If the delay requirements are different among applications U_{step} or U_{exp} can change their behavior based on T_{max} parameter. Following figure shows the decision when 60 LSPs are sent to the first node in the multi-hop scenario.

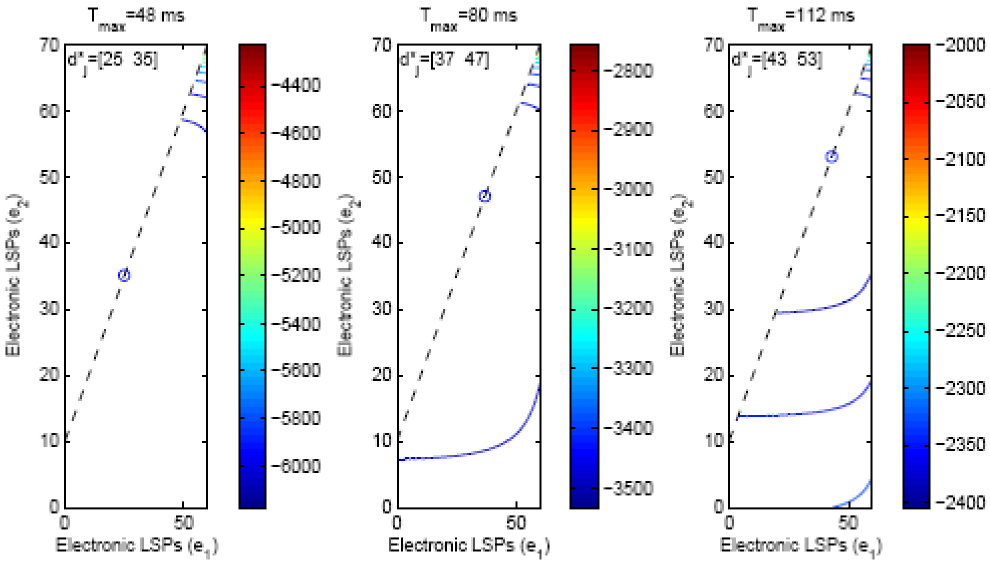


Figure 3: Variation of the T_{max} parameter for U_{exp} utility

Left subfigure shows the decision when T_{max} constraint are more strict (only 25 LSPs are sent through the electronic layer) and the right one shows that the decisor change its choice sending 43 LSPs when T_{max} value is 112 ms.

As we have seen through these examples, thanks to the T_{max} parameter, the operator can tune the LSPs QoS using the U_{step} and U_{exp} utilities. The R_{cost} parameter provides further discrimination capabilities, according to the total amount of resources and their cost.

5.1.3 Next steps

This decisor may be studied in complex network and compare this centralised solution with a distributed solution, where each node makes its decision according to its own parameters. Moreover, an extension of this algorithm to route the traffic based on risk metrics will be carried out.

5.2 RWA (routing and wavelength assignment) and regenerator placement (RP) in semi-transparent networks.

5.2.1 Performed activities

In the framework of this joint activity CTTC, UPC, AIT have performed focused studies that are covered in this section of the deliverable as follows.

The main goal addressed by CTTC in this JA consists in performing theoretical study and experimental evaluation on advanced IA-RWA algorithms for translucent optical networks in the context of the dynamic GMPLS provisioning. To this end, it is studied whether current GMPLS protocols (i.e., signaling and routing) are adequate to efficiently fulfil the requirements of the translucent IA-RWA algorithms. If this is not the case, it is identified the needed protocols extensions, which are then implemented and validated experimentally in the CTTC GMPLS-based ADRENALINE testbed. In this context, CTTC has realized the following research activities aiming at encompassing those objectives:

- Study and survey on optimal translucent IA-RWA algorithms for distributed GMPLS optical networks. In particular, such a survey gathers the main works produced in the dynamic provisioning of connection within translucent optical networks.
- Definition of the physical impairment model considered by the routing algorithm to deal with adequate optical signal quality. This model is based on monitored link and node OSNR levels, which from it is derived/computed an end-to-end OSNR level.
- Definition and implementation of the IA-RWA algorithm and the required translucent-oriented GMPLS protocol enhancements within the CTTC ADRENALINE testbed.

The main goal of the joint work developed by UPC with AIT within this JA has been the study and classification of the recent works in the literature addressing the IA-RWA (Impairment Aware Routing and Wavelength Assignment) problem. More than one hundred of papers have been reviewed and classified by at least two reviewers. For this purpose two mobility actions have been organized in the scope of this JA:

- AIT-UPC (Dates: 31.05-07.06 2008)
  Visitor: Mirek Klinkowski
  Host: Ioannis Tomkos (AIT)
- UPC-AIT (Dates: 06.07- 12.07 2008)
  Visitor: Siamak Azodolmolky (AIT)
  Host: Josep Solé-Pareta (UPC)

The tasks developed in these mobility actions have been:

- Structure and work plan for a survey paper on Impairment Aware Routing and Wavelength Assignment (IA-RWA) algorithms
- A detailed classification of IA-RWA algorithms
- Selecting the IA-RWA algorithms for comparative studies based on UPC and AIT's simulation platforms.

Result of these mobility actions is a survey paper that has been submitted to the Computer Networks (Elsevier) Journal in August 2008 [1], which at the moment has been accepted for near future publication.

Moreover we have continued collaborating in order to prepare a second survey paper with comparative results among the selected IA-RWA algorithm. For this purpose the activities developed have been:

- Implementation of the selected IA-RWA algorithms in the UPC's and AIT's simulator.
- Working on the interface between UPC's network simulator and AIT's physical and network simulators.

PoliMI and UPC have been working jointly in the proposal of new Impairment Aware RWA (IA-RWA) and Regenerator Placement (RP) algorithms for translucent networks. These proposals include schemes for the designing phase of the network; where the goal is to minimize the amount of resources (installed wavelengths in the links and needed regenerators in the nodes); as well as IA-RWA algorithms for the regular operation of the network with dynamic traffic, where the goal is to maximize the number of accepted connections.

Moreover these new proposals take into account the possibility that the IA-RWA algorithms manage inaccurate physical layer information during the regular operation of the network. The physical layer information utilized by the IA-RWA algorithms for computing the lightpaths can be inaccurate for different reasons: drifts of the physical parameters due to the aging of the equipments or due to dependences with the traffic load and also because physical parameters used in the designing phase are different from the current stored parameters in node databases. In this scenario the proposed IA-RWA algorithms have to be able to counteract the negative effects of using inaccurate information.

From this work two joint papers have been submitted:

- To the IEEE Networks Journal [2](August 2008)
- To the ONDN2009 conference [3] (September 2008)

5.2.2 Planned activities

The next activities of CTTC mainly rely on the evaluation and validation of the devised and implemented IA-RWA along with the GMPLS protocol enhancements considering different performance indicators, namely, connection blocking probability, average setup delay, etc. In addition, different dynamic traffic conditions will be evaluated. To this end, the following tasks will be addressed:

- Experimental assessment and evaluation of the IA-RWA algorithm and protocol extensions under different network node architectures such as full transparent, translucent with different number of 3R regenerators.
- The proposed IA-RWA algorithm will be also evaluated taking into account different sparse and strategic allocation of 3R regenerators within the network.

UPC and AIT will continue collaborating in order to perform comparative simulation studies of selected IA-RWA algorithms. These selected IA-RWA algorithms will be a sub-set of the algorithms presented in the previous survey joint paper. The objective of these studies is the preparation of a second joint publication (UPC-AIT) to report a performance evaluation of proposed IA-RWA algorithms in the recent literature for transparent and translucent optical networks. This comparative evaluation will be performed in terms of blocking probability as well as in terms of quality of the signal of the established connections.

There exists the possibility of a new mobility action between AIT and UPC in order to prepare this 2nd survey paper.

In the scope of this JA PoliMI and UPC will continue working in order to propose new IA-RWA algorithm for both, designing phase and regular operation. These new algorithms:

- will try to optimize the placement of nodes with regenerators in the case of the designing phase
- and for the regular operation with dynamic traffic will try to take into account those physical impairments that change with traffic load.

For this purpose, PoliMI has proposed to send a Master student to UPC in the framework of an Erasmus grant. This student will develop task related to the BONE project in his Master thesis as well as some required subjects in the Telecommunications school (ETSETB) in UPC. He will be supervised by Josep Solé Pareta and Eva Marín Tordera fromUPC:

5.3 Algorithms for multi-layer optimization with ICBR constraints.

5.3.1 Overview of main research results

Static planning with ICBR constraints

UPCT and AIT has been studying the static planning of OCS networks, subjected to the wavelength continuity constraint, and considering signal impairments. The interest is focussed on the design of optimization algorithms for this type of scenario, which make use of a common Q-evaluation function. Such a function, developed by AIT, provides the Q factor for a given set of lightpaths, established in a given network topology.

A set of algorithms has been proposed, and tested. UPCT has proposed a global search optimization algorithm which combine ILP formulations and heuristic approaches, while AIT is more focussed on heuristic approaches based on sequencing the lightpath demand. A join publication is being prepared. The collaboration work was promoted by the mobility action from UPCT to AIT of Ramon Aparicio Pardo, from the 15^{th} to the 26^{th} of April 2008.

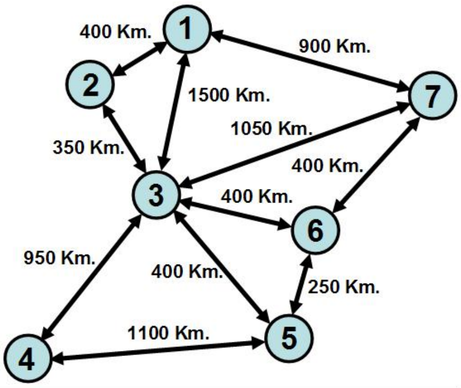
Static planning in multifibre networks

UPCT and TID collaborated in investigating the static planning of multifibre networks, where two neighbour nodes are connected with a bundle of K fibres, $K>1$. On one hand, the multifibre approach adds the cost of amplifying, equalizing, monitoring, switching, etc. more fibres. On the other hand, the WC approach involves the cost of one WC device per wavelength conversion (we assume that the WCs are shared per node). UPCT and TID compared in this work the interest of both approaches in the static planning case. For this, a binary ILP (Integer Linear Programming) formulation was proposed which simultaneously includes the cost of both alternatives. Then, we obtain the minimum cost solution under different conditions, and evaluate the actual use of WCs (wavelength converters) and/or multifibres.

We tested three networks of 7 nodes: a mesh network (Figure 4), a ring and a star with centre in node 3 (last two cases with fibres of 100 km length). In all the cases, links have two fibres, and 8 wavelengths per fibre. One fibre in the link is already pre-activated at cost 0. The cost of activation of the other fibre, normalized to one transmitter plus one receiver cost, is taken from NOBEL cost model: $20+0.96036(d/80)+1.585(d/360)$, where d is the link distance in km. Divisions are rounded to the floor, and correspond to optical line amplifiers, and dynamic gain equalizers per each 80 km and 360 km spans respectively.

The formulation has been implemented in the MatPlanWDM tool, which interacts with a TOMLAB/CPLEX solver. Let T be the 7x7 traffic matrix in Figure 1, obtained from traffic forecast studies for a national optical backbone (measured in Gbps). All the traffic matrixes used are calculated multiplying T, by a real factor. For each topology we made 20 tests with different traffic matrixes, from the higher traffic carried at 0 cost, to the higher carried traffic feasible found. As the WC technology is not fully mature, WC prices were estimated sweeping the WC cost from 0.01 (1% of a transmitter plus a receiver), to a sufficiently high value. Naturally, we expected a lower preference for WCs, as the WC cost grew. Surprisingly, as it is shown in Figure 1, WCs were not used in any case, even considering the lower WC cost of $c_{WC}=0.01$. As traffic grew, a higher number of fibres were activated. But always happened, that given a set of active fibres, if a solution with WCs was found, a solution without WCs and the *same active fibres* was found (obviously at a lower cost).

Previous studies showed that multifibre networks could reduce at a great extent the need of WCs for *dynamic planning* scenarios. Our tests correspond to static planning. It seems that the advantage of a deterministic knowledge of the traffic (in contrast to dynamic planning), greatly *favours* finding minimum solutions without WCs. After these results, we conducted more tests in these topologies which confirmed that minimum cost solutions with WCs in static planning are largely infrequent, and appear in very narrow intervals of traffic demands.



	1	2	3	4	5	6	7
1	0	13.30	23.53	8.10	13.52	22.81	20.59
2	4.28	0	22.91	7.89	13.16	22.24	20.07
3	23.53	73.69	0	43.03	71.88	121.47	109.70
4	8.10	25.28	43.03	0	24.66	41.69	37.67
5	13.52	42.26	71.88	24.66	0	69.66	62.90
6	22.81	71.41	121.47	41.69	69.66	0	106.30
7	20.59	64.50	109.70	37.67	62.90	106.30	0

	MESH net - 7 nodes			RING net - 7 nodes			STAR net - 7 nodes		
Matrix Index	Carried Traffic (Gbps)	No. Used WCs	No. Extra Activ. Fibres	Carried Traffic (Gbps)	No. Used WCs	No. Extra Activ. Fibres	Carried Traffic (Gbps)	No. Used WCs	No. Extra Activ. Fibres
1	953	0	0	368	0	0	338	0	0
2	1005	0	2	397	0	1	356	0	1
3	1057	0	3	425	0	3	375	0	2
4	1109	0	4	454	0	4	393	0	3
5	1160	0	5	483	0	4	412	0	3
6	1212	0	6	512	0	5	431	0	3
7	1264	0	6	540	0	6	449	0	4
8	1316	0	6	569	0	6	468	0	5
9	1367	0	7	598	0	7	486	0	5
10	1419	0	7	627	0	7	505	0	5
11	1471	0	8	655	0	9	523	0	6
12	1523	0	10	684	0	10	542	0	6
13	1574	0	11	713	0	10	561	0	6
14	1626	0	11	742	0	11	579	0	6
15	1678	0	13	770	0	11	598	0	7
16	1730	0	13	799	0	11	616	0	7
17	1781	0	15	828	0	12	635	0	7
18	1833	0	16	857	0	13	653	0	7
19	1885	0	16	885	0	14	672	0	7
20	1937	0	18	914	0	14	691	0	7

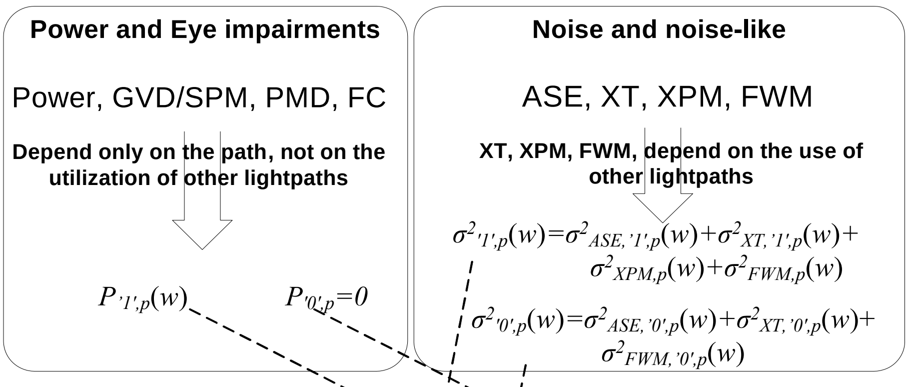
Figure 4: Network topology and assumptions

A mobility action was carried out from UPCT to TID, focussed on this topic: (15-26 April) From UPCT to AIT. Ramon Aparicio Pardo. A joint publication has been presented in [4].

Multicost Approach to Online Impairment-Aware RWA

In the context of this JA, RACTI performed a joint work with AIT and proposed a multicost algorithm to online impairment-aware routing and wavelength assignment (IA-RWA)[5].

In particular, to serve a connection, the proposed algorithm finds a path and a free wavelength (a lightpath) that has acceptable quality of transmission (QoT) performance by estimating the corresponding Q factor. Figure 5 shows the approach we have adapted in order to calculate the corresponding Q factor of a path.



$$P_{'1',p}(w) \qquad P_{'0',p}=0$$

$$\sigma^2_{'1',p}(w)=\sigma^2_{ASE,'1',p}(w)+\sigma^2_{XT,'1',p}(w)+\sigma^2_{XPM,p}(w)+\sigma^2_{FWM,p}(w)$$

$$\sigma^2_{'0',p}(w)=\sigma^2_{ASE,'0',p}(w)+\sigma^2_{XT,'0',p}(w)+\sigma^2_{FWM,'0',p}(w)$$

$$Q_p(w)=\frac{P_{'1',p}(w)-P_{'0',p}}{\sigma_{'1',p}(w)+\sigma_{'0',p}(w)}$$

Figure 5: Q factor calculation

Assuming that there are m available wavelengths, the cost vector of a link l is given by

$$V_l = (d_l, G_l, \overline{\sigma^2_{'1',l}}, \overline{\sigma^2_{'0',l}}, \overline{W_l}),$$

where, (i) d_l is the delay of the link– or its length (scalar), (ii) G_l (in dB) is the gain of the link (scalar), (iii) $\overline{\sigma^2_{'1',l}}=(\sigma^2_{'1',l}(1),..., \sigma^2_{'1',l}(m))$ is a vector with the noise variances of signal 1 for each of the wavelengths, (iv)

$\overline{\sigma^2{}_{'0',l}}$ =($\sigma^2{}_{'0',l}(1)$,..., $\sigma^2{}_{'0',l}(m)$) is a vector with the noise variances of signal 0 for each of the wavelengths, and (v) $\overline{W_l}$ =($w_l(1)$,...,$w_l(m)$) gives the availability of wavelengths in the form of a Boolean vector (element $w_l(i)$ is equal to 0 (false) when wavelength λ_i is used and equal to 1 (true) when λ_i is free (available)).

Similarly to a link, the cost vector of path p can be calculated by the cost vectors of the links l=1,2,..,k, that comprise it:

$$V_p = \left(\sum_{l=1}^{k} d_l ,\ \sum_{l=1}^{k} G_l ,\ \sum_{l=1}^{k} \left(\overline{\sigma^2{}_{1,l}} \cdot \prod_{i=l+1}^{k} 10^{G_i/10} \right),\ \sum_{l=1}^{k} \left(\overline{\sigma^2{}_{0,l}} \cdot \prod_{i=l+1}^{k} 10^{G_i/10} \right), \underset{l=1}{\overset{k}{\&}} \overline{W_l} ,(1,2,...,k) \right),$$

where the operator & denotes the bitwise AND operation.

The proposed multicost algorithm consists of two phases. In the first phase, the algorithm finds the set of so called non-dominated paths from the given source to all the nodes of the network, including the given destination.

In the second phase, an optimization function is applied to the cost vector of the paths, in order to find the optimum solution. More specifically, we have evaluated the following cost functions:

i) Most Used Wavelength (MUW)

Given the connections already established, we order the wavelengths in decreasing utilization order and choose the lightpath whose wavelength is most used. Note that this approach does not differentiate between the Q factors of the solutions, as long as they are feasible. So the chosen lightpath can have a Q value close to the threshold, which can become unacceptable when new connections are established.

ii) Better Q performance (bQ)

For each path and wavelength we calculate its Q factor and select the lightpath with the higher Q value. This approach does not consider the utilization of wavelengths in the network, making it more difficult for future connections to be served due to network-layer blocking.

iii) Mixed better Q and wavelength utilization (bQ-MUW)

We start by finding the highest Q, as in (ii). Then, we obtain the set of lightpaths that have Q close to that highest value. From this set we select the lightpath whose wavelength is used more in the network, as in (i).

Note that the noise variances corresponding to XT, XPM and FWM impairments depend on the utilization of the other lightpaths. Therefore, when a lightpath is established, the quality of transmission (QoT) of some already established lightpaths may become unacceptable, and the corresponding connections will have to be rerouted

To evaluate the performance of the proposed algorithm we conducted simulation experiments in Matlab. The experiments were performed assuming the DT network topology. To evaluate the feasibility of the lightpaths we use a Q-factor estimator that uses detailed analytical models to account for the most important impairments.

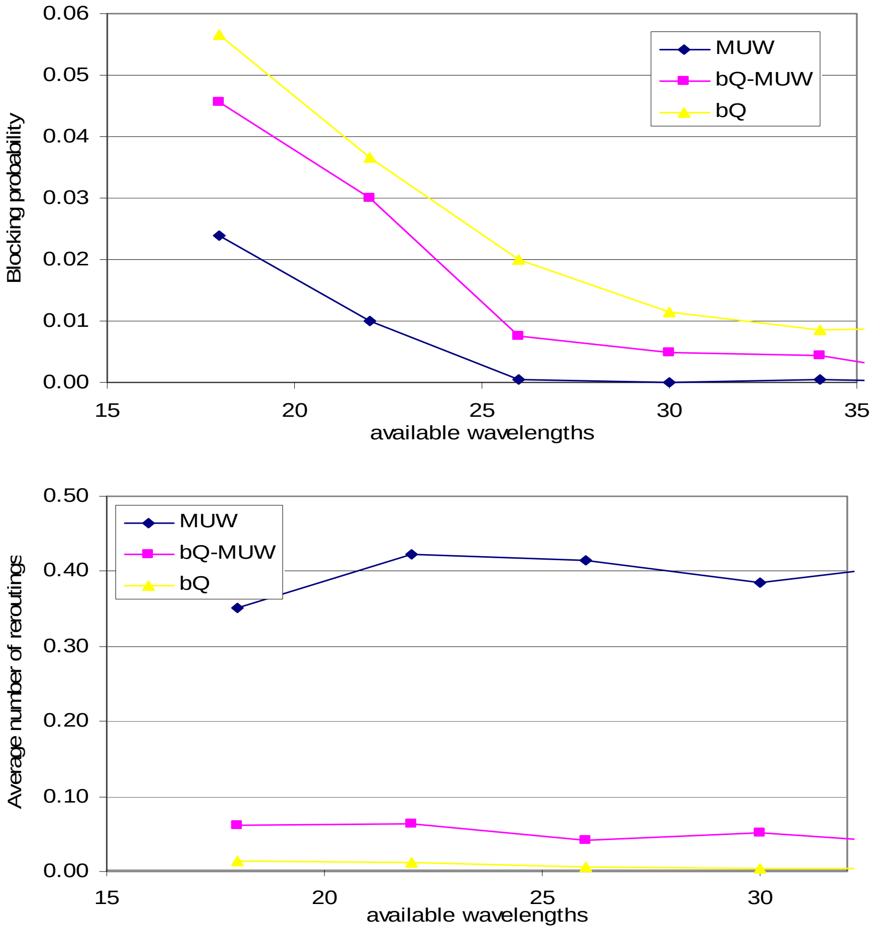


Figure 6: (a) blocking probability and (b) rerouting probability for uniform span length equal to 100 km.

In Figure 6(a) we graph the blocking probability for the three examined optimization policies. We can observe that the most used wavelength (MUW) policy exhibits the best performance. However, as Figure 6(b) indicates, MUW exhibits a high number of reroutings. On the other hand, the bQ policy has the worse blocking probability performance, since it wastes a lot of wavelengths trying to establish a lightpath that is not affected by the others. However, since the established lightpath has the highest Q value and future connections do not appreciably affect its feasibility, bQ exhibits the best rerouting performance. The mixed bQ-MUV algorithm that combines the good blocking probability of MUV algorithm and the low rerouting probability of bQ algorithm seems the best solution since it gives the most balanced results.

Concluding, our results indicate that the proposed multicost algorithm with an optimization function that accounts for both the availability of wavelengths and the Q performance of the chosen solution exhibits a superior performance, combining good physical-layer blocking and low rerouting rate of older connections. The execution time of the proposed algorithm is small, making it appropriate for serving online connections.

5.3.2 Planning future work

The partners intend to progress in their current lines of work during year 2 of the WP. Other partners in the JA, not specifically mentioned in this report, have been active in several discussions, and interested in the circulated results.

5.4 ICBR algorithm taking into account traffic grooming

5.4.1 Performed activities

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 aim of this JA is the joint optimization of traffic grooming and ICBR. It is assumed that in the optical layer, there is no signal regeneration, and the noise and signal distortion accumulate along a lightpath.

The joint work is divided into 3 phases:

- Phase 1: investigation the traffic grooming in an ICBR environment
- Phase 2: define new node architectures, new traffic grooming methods
- Phase 3: discuss and present results obtained for defined architectures and by using the developed models

During the first project year, we almost finished the phase 1 and partly undertook the work in phase 2. Several results have been obtained from different network scenarios and different network parameters. We have considered a 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 it can be chosen 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.

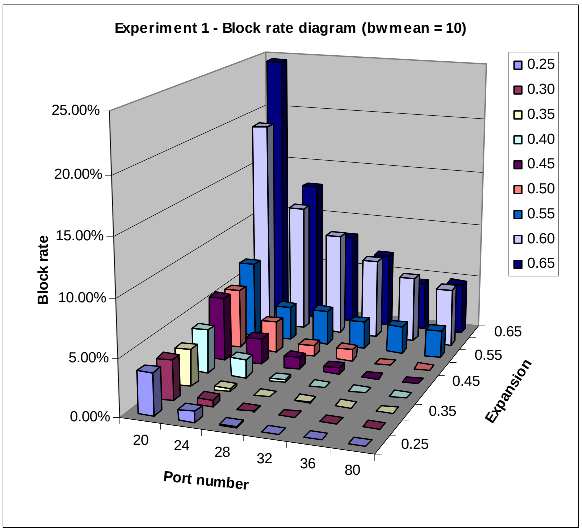


Figure 7 Blocking ratio vs. port number vs. expansion at 10 Mbit/s average demand bandwidth

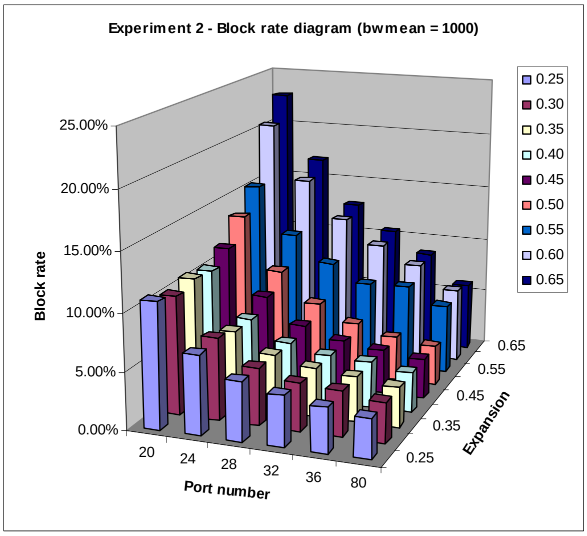


Figure 8 Blocking ratio vs. port number vs. expansion at 1 Gbit/s average demand bandwidth

To investigate the effects of Grooming in an ICBR environment it has been defined three crucial parameters. The first one is the scale of the network. We changed the used network link lengths by multiplying the original lengths with the scale parameter thus triggered the influence of physical impairments. The other parameter was the port number which means the number of electrical port in one optical node, e.g. the grooming capability of the node. The third parameter was the average bandwidth considering a fix bandwidth for every lightpath. The third parameter is also a metric of the grooming capability of the network. This means a 3 dimensional simulation space, whit a huge computation request. As a solution, a Hungarian supercomputer has been used to perform these simulations.

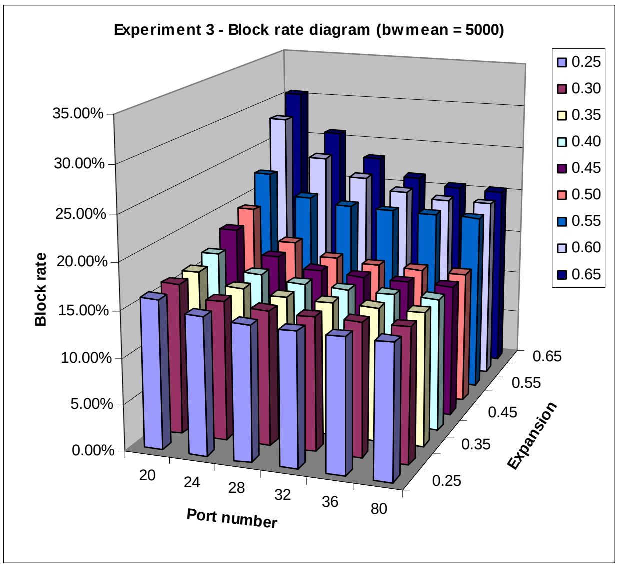


Figure 9 Blocking ratio vs. port number vs. expansion at 5 Gbit/s average demand bandwidth

The results show that while increasing the network size or decreasing the port number or increasing the average bandwidth of demands the blocking ratio decreases.

As conclusion in this JA we have shown so far how can the physical impairments and the limited number of O/E/O ports be taken into account while routing the demands in a grooming capable two layer network. We have turned attention to the mutual impact of grooming and physical impairments, i.e. of using the electronic time- and space-switching capable layer for signal regeneration and better resource utilization. We have shown, that having too few O/E/O ports leads to a significant performance deterioration, while having more O/E/O ports than a certain number does not change the performance at all, since they will not be used at all. The outcome of the joint research activity are reported in [6] and [7].

5.4.2 Planned activities

The work on phases two and three will be continued and if indicated, the set of considered architectures will be extended. We envisage publishing of results in scientific journals (OSA, IEEE, Elsevier) and conferences (ICTON, ECOC).

5.5 Traffic Engineering in Integrated and Interconnected Control Plane Models in the Presence of Physical Impairments

5.5.1 Performed activities

The main goal of this JA is to investigate TE applications and their effectiveness, for different control plane models in the presence of physical impairments; and to develop new TE schemes that take physical impairments into consideration when deciding the TE actions.

So far, Bilkent and BME have developed TE strategies for vertical interconnection and vertical integration control plane models on a common simulation platform. The results are published on a joint paper in the conference Networks 2008 [8].

In the vertical integration model, a unified control plane operates both the electronic and the optical layers. In the proposed TE scheme for this model, the traffic demands are routed by a single control plane that is capable of applying grooming. In TE scheme for the vertical interconnection model, the electronic layer requests static lightpath connections (with single wavelength granularity) from the optical layer and routes the traffic demands on the resulting logical topology. When resources of the constructed logical topology are insufficient to satisfy the introduced traffic, some of the requests are rejected.

In the context of this JA, a new "Shared Intelligence" TE scheme is also proposed for the vertical interconnection model. In this scheme, the electronic and optical layers act collaboratively to route the traffic demands. The electronic layer requests from the optical layer, static optical connections with sub-wavelength granularity. The traffic demands are routed by the electronic layer on the static logical topology that is composed of these optical connections. When the resources of the logical topology are insufficient to route an incoming traffic demand, a temporary optical connection between the source and destination of that demand is requested from the optical layer. Routing of that connection is achieved solely by the optical layer using the available physical layer resources.

The implementation of the static logical topology design part of the Shared Intelligence TE scheme is completed. The implementation of the collaborative routing feature in the simulation tool is currently going on and performance comparisons with the already implemented TE schemes will be carried out as soon as this part is completed.

5.5.2 Planned activities

The developed simulation tool for this JA is able to calculate the transmission quality degradation caused by the physical impairments including PMD, and ASE and crosstalk noises. The optical layer control plane is capable of performing routing and wavelength assignment by satisfying given transmission quality constraints. Hence, the proposed TE scheme for the vertical integration model takes the physical impairments into account.

In the TE schemes for the vertical interconnection model, the electronic layer control plane has no information on the physical layer and this fact may cause inefficient or infeasible connection requests from the optical layer control plane; and thus waste of the network resources. The next step in the schedule of this JA is the introduction of "information sharing" between the control planes, to improve the efficiency of the vertical interconnection TE schemes. This will be achieved without revealing the details of the physical topology to the electronic layer. To this aim, the optical layer control plane will announce a cost to the electronic layer control plane for the connection requests between each node pair. These costs will be determined according to the physical topology and the physical impairment factors.

The final objective is to compare the performances of the developed TE schemes under physical impairment conditions and investigate the improvement brought by considering the physical impairments also in the electronic layer, by using the proposed information sharing model.

6. Conclusions

During the first year of BONE project, five joint activities were running and active and new joint activities are compiled and distributed among all partners in order to initiate new joint activities during the next year of this work package. The current joint activities are: Multi-layer algorithm using Bayesian decision theory, RWA (routing and wavelength assignment) and regenerator placement (RP) in semi-transparent networks, Algorithms for multi-layer optimization with ICBR constraints, ICBR algorithm taking into account traffic grooming, Traffic Engineering in Integrated and Interconnected Control Plane Models in the Presence of Physical Impairments. Six conference/workshop papers and two journal papers are the dissemination outcome of these joint activities. The publications are referenced throughout this deliverable and are also compiled in the reference section (below). Four mobility actions are also performed during the reporting period of this TP. Details of these mobilities are as follows:

Introduction of ICBR constraints in multilayer optimization algorithms
Ramon Aparicio-Pardo, PhD Student at UPCT, hosted by AIT from 15/04/2008 to 26/04/2008
Status: Approved. Completed

Routing and Wavelength Assignment (RWA) and Regenerator Placement (RP) in semi-transparent networks
Miroslaw Klinkowski, PhD at UPC, hosted by AIT from 31/05/2008 to 07/06/2008
Status: Approved. Completed

Routing and Wavelength Assignment (RWA) and Regenerator Placement (RP) in semi-transparent networks
Siamak Azodolmolky, Researcher at AIT, hosted by UPC from 06/07/2008 to 12/07/2008
Status: Approved. Completed

Effects of ICBR constraints in multilayer optimization algorithms.
Ramon Aparicio-Pardo, PhD Student at UPCT, hosted by TID from 06/07/2008 to 12/07/2008
Status: Approved. Completed. Report not available yet

In addition to the currently running JAs, the following list of proposed research topic will be also circulated among the participants in order to start new joint activities during the second year of project.

No.	Description	Status
1	Algorithms for multi-layer optimization with ICBR constraints	Active
2	Physical Impairmet Aware Network Planning/Engineering	Proposed
3	Performance Evaluation of IP over optical networks	Proposed
4	Performance evaluation of Optical Performance/Impairment monitoring Techniques	Proposed
5	Performance Evaluation of Impairment Aware Control Plane (GMPLS-based and/or PCE-based)	Proposed
6	Multi constraint and dynamic lightpath routing in translucent optical networks	Proposed
7	Integration of Ethernet-based access and aggregation networks with the optical domain using and unified and integrated control plane	Proposed
8	Performance evaluation of physical information dissemination techniques on routing protocols	Proposed
9	The impact of moudlatoin formats on physical impairments	Proposed
10	Dynamic bandwidth allocation and MAC layer consideration for overlaid services in PON networks	Proposed

11	Impact of cross-layer optimization on power consumption	Proposed
12	Impact of grooming and physical impairments on routing/traffic engineering and resilience actions	Proposed
13	Multi-layer algorithm using Bayesian decision theory	Active
14	RWA (Routing and Wavelength Assignment) and RP (Regenerator Placement) in semi-transparent networks	Active
15	Traffic Engineering in Integrated and Interconnected Control Plane Models in the Presence of Physical Impairment	Active
16	Cross-optimization for impairment aware routing and wavelength allocation considering both electrical regenerator placement and grooming nodes placement	Active

7. References

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[2] Guido Maier, Eva Marín, Marco Quagliotti, Walter Erangoli, Giovanni Tamiri, Marcelo Yannuzzi, Xavier Masip, Sergio Sánchez, Josep Sole, "Cross-Layer Control of Semi-Transparent Optical Networks under Physical-Parameter Uncertainty", submitted to IEEE Networks, special issue (August 2008).

[3] Marcelo Yannuzzi , Marco Quagliotti, Guido Maier, Eva Marín, Walter Erangoli, Giovanni Tamiri, Xavier Masip, Sergio Sánchez, Josep Sole, "Performance of translucent optical networks under dynamic traffic and uncertain physical-layer information", submitted to ONDM2009 (October 2008).

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[6] Szilárd Zsigmond, Marcell Perényi, Tibor Cinkler „Cross-Layer Optimization of OSNR-Constrained RWA in WDM Optical Networks" COST 291 workshop on The role of optical networking in the future Internet Vilanova i la Geltrú, Catalonia, Spain, Spain, March 11, 2008.

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