A Survey on Impairment-Aware Dynamic Routing and Wavelength Assignment

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Optical Networks play a major role in supporting the heavy traffic in communication down the line. Routing and Wavelength Assignment (RWA) is the technique used to establish the light-path between a source-destination pair which carries the data in a wavelength routed all-optical network. Further, as the optical signal travels through the light-path to its destinations in the optical network, the quality of the signal degrades due to the lack of regeneration, which results in increase of Bit-Error-Rare (BER). With the increase in BER the light-path becomes inefficient in communication. Considering the dynamic light-path establishment with physical layer impairment raised a complex problem. Integer Linear Programming was used in computing the answer to the problems and many approaches were by made the researchers. I have mainly concentrated on dynamic routing and wavelength assignment and presented a detailed analysis published by various researches.

Categories and Subjects Descriptors:

General Terms: Optical networks, Routing and wavelength assignment, Quality of signal, Impairment aware, light-path.

Additional Keywords and Phrases: Quality of service (QoS), Quality of transmission (QoT), Online/Dynamic Routing, Optical fibers, Translucent, Transparent, Wavelength.

Contents

1. INTRODUCTION

An optical signal degrades in it quality due to the impairments present in the optical fiber while propagating through the light-path. Due to the low Quality of Transmission (QoT) some of the light-paths fail in communication. Because of this reason, Impairment-Aware Routing and wavelength assignment has come into the picture. This survey is important as its provides a deep discussion on the topic of Impairment aware Routing and Wavelength assignment. As the quality of the signal degrades while propagating through the lightpath, much work was carried out by many researchers for many years. This survey has a collection of 10 on topic papers and gives a brief description .

This survey gives a discussion on the topic of Impairment aware dynamic routing and wavelength assignment. Relevant research papers were found by searching Google Scholar with the keywords "Impairment aware routing" and "wavelength assignment", "Online RWA", etc. The keywords and author names were used to search the ACM publication library, IEEE and LNCS. A total of 10 papers was selected in this survey. This survey contains 7 journal papers, and 3 conference papers, which are closely related to this survey were identified. They are listed in the bibliography.

The remainder of this survey is structured as follows:

Section 2 contains reviews of 10 papers: Subsection 2.1: [Pachnicke et al. 2009], [Potou et al. 2010], [Christodoulopoulos et al. 2011]. Subsection 2.2: [Qi et al, 2008], [Adami et al. 2011], [Hirata et al. 2012], [Hirata et al. 2012], [Angelou et al. 2012], [Azodolmolky et al. 2012]. Subsection 2.3: [Rahbar. 2010].

Doing the survey on this topic was quite interesting and had given me a lot of deep knowledge in optical networking. This was very surprising that I have found lot of papers on optical network and on my topic I found more than 20 papers. Then latter I have filtered out 10 papers which were exactly on my topic.

2. RESEARCH CATEGORY

2.1 Online Physical layers Impairments in Translucent and Transparent

In this section we will be discussing about 3 papers, [Pachnicke et al. 2009], [Potou et al. 2010], [Christodoulopoulos et al. 2011].

2.1.1 Approach considering Quality of Transmission in Translucent

[Pachnicke et al. 2009] address the problem that quality of transmission (QoT) goes down with the network load and change of channel. In large dimensional translucent optical networks (pan-European Networks) the quality of the signal is very important in transparent paths. Due to the high cost of 3R regenerations, limited regeneration sites are deployed.

The authors do not refer to any previous work.

The authors [Pachnicke et al. 2009] present a novel online constraint-based routing (CBR) algorithm using the present channel load in properly modeling

the inter channel effects, guarantee connection and will give the minimum signal quality when new connection is established. This CBR algorithm considers linear and Non-linear impairments.

In Mesh topology, the authors have chosen COST266 European core network with 28 nodes and 42 bidirectional edges. No physical parameters are assigned hence span lengths are selected by heuristic approach with the assumptions by networks in generating the replacements for the missing data. A dispersion pre-compensating with -650 ps/nm was deployed. Author assumed that the polarization mode dispersion values in the forward and backward would be same as the fibers were from the same cable with similar properties. A channel plan with a highest of 40 wavelengths per link was placed with 50GHz. The EDFA was set, a noise figure value was assumed. And stated the minimum Q-factor was required in the study.

[Pachnicke et al. 2009] presents their results using graphs. Author compares CBR algorithm to a commonly used shortest path routing with high transparent reach. The result shows that nearly 3000km was need to get the same performance. Shorter transparent reach results high blocking probability. For a assumed simulation there are good communication in long pat and bad quality in short path. Finally, the result show that shortest path routing will results to high blocking probability compared to offline and online CBR algorithms.

[Pachnicke et al. 2009] claim to have undertaken a new study of a new online constraint based routing (CBR) algorithm considering the QoT. This algorithm gives the accurate assessment for the nonlinear degradation effects by considering the present network load. The authors states that they algorithm is superior to the shortest path routing and also outruns a CBR algorithm in worst case transmission.

2.1.2 Approach considering Amplifiers power constraints.

The author [Potou et al. 2010] states that the signal quality degrades as it propagates through the network in the wavelength routed optical network.

The author did not refer to any previous work.

The author presented an extension of multicost impairment aware online algorithm to include amplifier power constraints. This extended algorithm covers possible saturation of amplifers that changes when a new connection is established in the link. In terms of blocking probability and rerouting frequency this extended algorithm preforms better compared to that of previous proposed algorithm. The performance of the algorithm is evaluated with power constraints algorithms in matlab. The Q-factor of the new and established light-path is calculated by using Q-factor estimator tools and determines the unacceptable transmission quality. The optimum light-path is chosen by using Q policy. The algorithm has two phases, before the first phase the cost parameters are given and the cost vector is created by calculating the amplifier gain and noise variance. In the first phase a set of non-dominated Q paths are found from the source node to other all nodes in the network. The path which is dominated by the other path has the least delay, availability of wavelength and QoT than another path, and if there is no further extension there will be no path. In this

way the algorithm will have at least one wavelength available and that wavelength will have the least acceptance of Q-factor performance. In the second phase the optimum solution is found by applying the optimization function to the cost vector. In order to choose the optimal lightpath for a connection various objective functions evaluated and proposed. To have a procedure of rerouting, it has to check the amplifier gain for variations as QoT of the other already established lightpath may be unacceptable. The author [Potou et al. 2010] states that the rerouting for the IA-RWA with the power constraints are relatively small so the execution time of the algorithm with and without rerouting is almost similar. And even the two algorithms for rerouting and available 50 wavelengths have same execution time. As IA-RWA algorithm performs many reroutings and while IA-RWA with power constraints performs a less number of reroutings and need more time to evaluate the gain of amplifiers. [Potou et al. 2010] claims that the total output gain of the amplifier is saturated as to higher the input signal power which uses the wavelengths. The algorithms can lower the blocking probability for a new connection and for already established connection it lowers the rerouting probability.

2.1.3 Approach using Indirect and Direct Multicost algorithm.

[Christodoulopoulos et al. 2011] states that due to the physical layer impairments the quality of the signal degrades, the algorithms should also carry out to serve a new connection, find a route and free the wavelength. And also due to the effect of interference the light will affect and get affected by the other light-path while establishing the new light-path.

The author did not refer to any previous work.

[Christodoulopoulos et al. 2011] has come up with two multicost algorithms which stand as a solution for interference effects, physical effects, a cross layer optimization between network and physical layer. The first algorithm evaluates the quality of the candidate light-path with combination of scalar paths, uses the cost vectors with impairment creating source parameters which would be applicable for physical settings. In second algorithm the physical models are used to define noise variance which is related with the cost parameters for calculating the Q-factor of the candidate light-path. These algorithms will find the set of non-dominated paths which help the connection thinking that no other path is better in the set reference to cost parameters.

[Christodoulopoulos et al. 2011] have used MATLAB in carrying out the simulation experiments for evaluating the performance of the algorithms. A transparent candidate network recognised by DICONET project, Generic DT network topology simulations were performed. The detailed analytical models used but Q-factor estimator for evaluating the feasibility of selected light-path. The unacceptable QoT is known by calculating the Q-factor with the help of Q-Tool taking the input as new and presently established light-paths. The request connection for a single wavelength is produced with respect to a Poisson process with rate λrequest/time. The source destination is uniformly chosen from among all nodes. Also the authors carried out the experiments on tuning the parameters of the Multi-Parametric Algorithm, in comparing the performance

of the Multicost Algorithms and random networks experiments.

The experiments were carried out for evaluating the scalability of the IA-RWA algorithms. 10 Random networks with 40 networks in total were created and connectivity degree is 3.5. For every network the number of hops of the longest path should be found and a distance should be set between two adjacent nodes which is 1200KM. The author have represented in result graphically which states that blocking probability and the running time for feeding a single connection, average of 10 random networks for each value of N. The blocking probability decreases as the number of nodes increases as the same load is divided with the larger network and the congestion link is low. With that of the MP algorithm the SC algorithm exhibits the best blocking performance. With the node of node the average running time increases.

[Christodoulopoulos et al. 2011] claims that these algorithms can efficiently assist the online traffic in transparent network with guaranteeing the quality of transmission of light-path with as low running times.

Year	Title	Authors	Major contribution
2009	Online Physical-Layer Impairment-Aware Routing with Quality of Transmission Constraints in Translucent Optical Networks	Stephan Pachnicke, Nicolas Luck, Peter M. Krummrich	The author has introduced two multicost algorithms which stand as a solution for interference effects, physical effects, a cross layer optimization between network and physical layer..
2010	Dynamic Routing and Wavelength Assignment in Transparent WDM Networks with Amplifiers' Power Constraints	K.Potou, K.Manousakis, K. Christodoulopoulos, E. Varvarigos	The authors present a novel online constraint-based routing (CBR) algorithm.

2011	Indirect and Direct Multicost Algorithm for Online Impairments-Aware RWA	Konstantinos christodoulopoulos, Panagiotis Kokkino and Emmanouel Manos Varvarigos	The author presented an extension of multicost impairment aware online algorithm to include amplier power constraints.

2.2 Online Physical layer Impairments with Multifibers and others.

In this section we will be discussing about 6 papers, [Qi et al, 2008], [Adami et al. 2011], [Hirata et al. 2012], [Hirata et al. 2012], [Angelou et al. 2012], [Azodolmolky et al. 2012].

2.2.1 Approach in Multi-granularity network

The author [Qi et al. 2008] addresses the issue regarding the transmission of the optical signal. The Optical signal will be degraded due to impairments mainly because of the number of multi-granularity optical cross-connects and the fiber links. These impairments cause a bit-error rate which is unacceptable.

The authors refer to the previous work Qi et al. [2006].

The author in [Qi et al. 2008] has presented a model to study the impacts in transmission impairment on the quality of signal in multi granularity optical WDM networks. The losses of optical signal are due to the fiber/waveband/wavelength switches, multiplexers, demultiplexers and fiber links. A novel dynamic transmission impairment-aware RWA heuristic algorithm is proposed based transmission impairment model. This RWA algorithm takes the effects of transmission impairment when a multi granularity LP was setup to carryout waveband routing in network layer.

MNWR-TIA algorithm in the network topology for the dynamic traffic demand it represented in a diagram. Based on the MNWR-TIA algorithm both serial MG-OXCs and interconnecting MG-OXCs were simulated. The poisson distribution for an incoming request was assumed and with a negative exponential distribution the connection request limitation was satisfied. And for more simulation of the equation author referred to Qi et al. 2006.

The blocking probability for both the MG-OXCs network was increased while the network traffic load was increasing. The interconnecting MG-OXCs acquire better blocking act which was benefited from integrity and flexibility for the interconnecting architecture compared with serial cascaded MG-OXCs.

[Qi et al. 2008] claim that the MNWR-TIA algorithm can support guaranteed signal quality lightpath in WDM networks and the interconnecting MG-OXCs network has a very low blocking probability compared to that of serial cascaded MG-OXCs.

2.2.2 Approach in QoT and Survivability

[Adami et al. 2011] states that the Wavelength Routed Photonic Networks are imperfect in adapting the classic Routing and Wavelength assignment solutions .And the author address the issues like physical impairments and Quality of transmission, process and delay time, Light-path constancy and Minimum resource allocation ,the solutions of the Routing and Wavelength Assignment are not sufficient to be used by Wavelength Routed Photonic Networks (WRPNs), these networks would play an important role in future internet applications. Even in network failure QoT should be guaranteed in light-path transmission.

The author do not refer to any previous work.

[Adami et al. 2011] has proposed an algorithm in his previous work Adami et al. [2010] without considering the resilience. In this paper the authors have come up with two new algorithms to support the critical services in Wavelength Routed Photonic Networks. The main objectives of these two algorithms are to protect with assured QoT and to minimize the resource allocation. The first algorithm uses on-the-fly multipath RWA with calculation referred by Dijkstra Algorithm and the second algorithm uses Suurballe algorithm. The results are compared with IA-RWA survivable algorithm Markidis et al. [2009]. The authors stated that this algorithm strictly provides either 1+1 or 1:1 protection. The single cut fiber cut and critical services of WRPNs are designed with redundant hardware. The main aim of these algorithms is to guarantee QoT and survivability in single link failure case, the complexity of these algorithms is lower and setup delay of the light-path is reduced. These algorithms named MCP- D^2 and MCP-S, inherit the main features of MCP-RWA algorithm and improve the survivability support. MCP- D^2 will calculate the primary and the secondary light-paths by applying the MCP-RWA algorithm twice. Once for the original topology and then residual network to primary light-path after all links are cut short. In MCP-S, they use suurballe algorithm in calculating a pair of disjoint light-paths on available wavelength. By using the two disjoint light-paths of same wavelength decreases blocking in future by removing trap topology problem and my decreasing the wavelength fragmentation.

The proposed algorithms performances was evaluated by comparing with $(D+FFWO)^2$. Firstly the primary light-path was computed using Dijkstra algorithm. Then a wavelength was assigned for a primary light-path using FFwO heuristic and then QoT was evaluated. Then the links of the primary light-paths were cut short from the topology. And then the backup light-path is computed and impairments are validated by repeating the same process used in the first phase.

When there are less number of connection requests, $(D+FFWO)^2$ will have the lowest processing time irrelevant of the network. The new algorithm decreases when there is increase in number of connection request. This is done due to the IA-RWA process of MCP-D^2 and MCP-S which remove the unusable WG. It is important that to highlight the processing time required in computing the path is just fraction of overall light-path setup time, which includes signalling and configuration time. Hence MCP-D^2 is the best choice as it ensures lowest blocking probability and higher processing time.

[Adami et al. 2011] state that the algorithm achieves the better blocking probability, and requires less processing time. Hence the algorithm is designed to give absolute QoT and hundred percentage survivability even in the single failure and to minimize the resource allocation. The chances of blocking the future requests and in reducing the setup delay. This was achieved by combining the high parallelizable multipath IA-RWA procedure with simple and effective heuristics.

2.2.3 Approach considering wavelength conversion cabability

[Hirata et al. 2012] states that in multi-fiber WDM network every link is with multiple fibers. Hence we can establish multiple light-paths with the same wavelength in the same link only possible in different fiber. A scheme was needed to efficiently use the multi-fiber and wavelength conversion. The authors have proposed a new scheme for it.

The author referred to previous work Rahbar. [2010].

[Hirata et al. 2012] has proposed a new scheme which is capable for providing the RWA for multi-fiber WDM networks with sparse and highly capable for full wavelength conversion. Based on the wavelength availability and the location of the node with capability of wavelength conversion, a route and wavelength are selected for every light-path. A path which does not share a same link and a wavelength is selected from the pre-defined routes between sender and receiver node. Then each path is divided into segments between nodes with wavelength conversion. The generation of bottleneck links and need of the specific wavelength is avoided by selecting the route from predefined paths and assigns the wavelength for a selected path. The scheme will select a path from a set of predefined link disjoint paths. And to create those predefined paths, an algorithm will be adopted for every pair of sender and receiver node. Firstly using Dijkstra's algorithm, scheme finds the shortest path from the source to destination, and opt the path as a link disjoint path. The scheme will now find a new shortest path on a graph and a path is opted as a new link disjoint path. Till there are routes from the source to destination this process is repeated.

In order to evaluate the scheme the author has conducted simulation experiments with the network topology. They have taken a network with 24 nodes and 43 bidirectional links, and with N wavelength conversion. Suppose the value of N is 24, full wavelength conversion capability is present in the network. For low complexity a propagation delay of every link is 0.1 and the processing time is 0.01. The author calculated the simulation results of the spare wavelength conversion, full wavelength conversion network and with no wavelength conversion network.

The author [Hirata et al. 2012] claims this scheme work great in networks with and without full capability of wavelength conversion, and that they have showed the robustness of the scheme with wavelength at each fiber, number of fibers at each link etc. In future author claims that they will consider the physical layer impairments.

2.2.4 Approach considering Backward Reservation.

[Hirata et al. 2012] states that due to the coarse granularity and wavelength continuity constraint for establishment of light-path the probability of blocking are very high in wavelength routed WDM network. This is very much critical issue which must be resolved. This could be reduced by introducing, multifiber where each link consists of multiple fiber, and by better RWA algorithm. The author in this paper proposed an RWA algorithm.

The author referred to previous work Rahbar. [2010].

The author [Hirata et al. 2012] came up with the new Dynamic RWA scheme with signalling the backward reservation for multi-fiber WDM network. In this scheme when the request for the new light-path arrives the collection of information is done between the source node and the destination node, by signalling backward reservation along multiple routes. Now the scheme will select a mixture of route and wavelength at the destination node with the help of information collected where the bottleneck links and the need of a specific wavelength can be avoided. This scheme helps in reducing the blocking probability in establishing the light-path. The experiments were carried out in constructing the predefined paths, information collecting by signalling and selection of Route and wavelength. In constructing the predefined paths the simple algorithm is used where firstly a shortest path is found from source to destination with Dijkstra's algorithm. And link is removed along the path from graph this process will be repeated till there are no routes from source to destination. In collecting the information, whenever the new light-path request raises PROB message is sent from sender node to receiver. The receiver will wait till it gets all PROB messages, then based on the information collected by PROB messages the receiver node will select a route and wavelength. Then the receiver will send the RESV message to sender from the selected route in establishing the light-path with selected wavelength. In route and wavelength selection the combination with low cost is selected by receiver node. The new light-path establishment is blocked if the cost is infinity. The scheme selects the shorter hops if there are more than two combinations with minimum cost. The blocking probability of establishment of light-path as a function offered load is represented in a form of graph. The blocking probability of light-path establishment is stated as a ratio of number of blocked light-path setup request and the total number if lightpath setup request. The blocking probability of SR is quite high as the wavelength availability in the network and bottleneck links are not considered. This scheme reduces the blocking probability as it effectively uses wavelength resources. It selects a combination from more candidates and wavelength resources are efficiently used by proposed cost function. The author [Hirata et al. 2012] claims that this scheme avoids the generation of bottleneck links and need of that a wavelength.

2.2.5 Approach in DICONET

[Angelou et al. 2012] states that network design and the operation are the major impact in optical transparency. In order to deal with physical-layer effects that's degrades the Quality of transmission (QoT) a European DICONET was

addressed to meet these challenges. In this paper the author have proposed and came up with good solution which smoothens transmission.

The author referred to previous work Christodoulopoulos et al. [2011]

[Angelou et al. 2012] states that the key features of the DICONET solution by showing some of the achievement of the project. In DICONET a set of cross layer optimization algorithms are designed in order to serve the network while planning and operation. These algorithms are combined in one software platform where the DICONET NPOT considers the impacts of physical layer impairments. The DICONET network solution is effectively supported by control plane in developing the generalised multiprotocol switching and allowing to the different entities run in the orchestrated manner. The completion of the project was done with implementing the multilevel integrated solution in DICONET testbed and practically realizing the vision for an end to end connectivity, dynamicity and reliability. The testbed was used for experiment and test the performance of two architectures with respect to lightpath to and fro dynamically. The distributed scheme outputs the lower setup times in high dynamic traffic condition with the benefit from parallel establishment of lightpath. The better blocking ration is justified by impairment aware routing process in centralised scheme. This centralised scheme allows the routing engine to have a complete view of the physical layer and the condition of traffic. But only one connection request can be served at one time, hence increasing the setup time. And strategy is implemented to improve the setup time of the lightpath for centralized scheme. With the dynamicity offered by integrated solution the DICONET will properly react to the failure and restoring the traffic which is affected in transparent fashion. To evaluate these things the centralised configuration is done where the failures occur randomly in the network. A set of predefined active paths were loaded in the network and by randomly eliminating the link cuts the independent failures. The result indicated as the fast restoration times even though there was sequential processing of lightpaths. Finally the result showed that in less than 5s the 72 percent of lightpath were restored.

The author claims that in order to achieve the resource optimization in future exible networks more investigation should be done in the issues like signal evaluation with advanced transmission parameters and allocation of dynamic bandwidth.

2.2.6 Approach using a tool for DICONET

The main problem the author addressed in [Azodolmolky et al. 2012] is the quality of the signal degrades as it propagates due to various types of distortions. Hence the DICONET project was introduced, the main aim of DICONET is to design and develop a physical layer impairment-aware Network planning and Operation Tool that link the performance of optical layer to IA-RWA, placement of the components and the algorithms which handle the failure. [Azodolmolky et al. 2012] presented the planning and major building blocks of DICONET NPOT. And also briefly explained the schemes that accommodate NPOT into the IA- GMPLS based control planes. The integration part was explained considering two approaches namely Centralized and Distributed Approach. In the centralized approach IA-RWA and the failure management are been carried out

while the OCCs executes the GMPLS protocols and blend to the main optical nodes. In distributed approach both RSVP-TE and OSPF-TE protocols were bound to allow the impact of PLIs with many understandings between network performance, control overhead and the complexity. The wavelength availability information is distributed by extending the OSPF-TE protocol. Each node is considered as an instance of NPOT which is connected to OCC through NPOT-OCC protocol. New connection request, to compute the k-shortest path, the source not request the online IA-RWA module of NPOT. [Azodolmolky et al. 2012] has selected Deutsche Telekom's national network for carrying out the experiments. DTNet has 14 nodes and 23 bidirectional links, node degree of 3.29 and length of the link 186KM average. No light-path longer than 1500km and agreeable QoT, without taking the impact of present light-paths. The NPOT in planning mode is evaluated with the ratio of number of light-paths demands and number of pairs of nodes. The performance results gather from planning and operation modes of DICONET NPOT were presented by the author. In NPOT planning all the demands were served with any blockage for every load values. The Rahyab module requests Q-tool to check the performance of each light-path to provide the minimum QoT on current light-path. Hence the computation time is high on NPOT. Where as in Operation mode when there is more connections request the ration of success in connection decreases though there are many channels available. The execution time of MP algorithm increases due to more available channels. Before the new light-path is established the Q-factor value of all the light-paths has to be calculated which intern result increasing the total execution time.

[Azodolmolky et al. 2012] claims that the main contribution of the DICONET project is designing and development of a network with PLIs aware planning and operation tool. NPOT exist in core network nodes including the physical layer's performance when planning and operation.

Year	Title	Authors	Major Contribution
2008	Impairment -Aware Dynamic RWA algorithm in Multi-Granularity WDM Optical Networks	Yogmin Qi, Yi Zhu, Tianshu Wang, Xuefang Zhou, Sheng Qian and Qiliang Li.	In this paper the author investigate on impacts of transmission of optical signal in multi-granularity WDM optical network

2011	Online Lightpath Provisioning and Critical Services: New IA-RWA Algorithms to Assure QoT and Survivability	Davide Adami, Stefano Giordano, Michele Pagano, and Luiz Gustavo Zuliani	In this paper the authors have come up with two new algorithms to support the critical services in Wavelength Routed Photonic Networks.
2012	Dynamic Routing and Wavelength Assignment in Multifiber WDM Networks with wavelength Conversion Capability	Kouji Hirata and Dewiani	The author has proposed a new scheme which is capable for providing the RWA for multiber WDM networks with sparse and highly capable for full wavelength conversion.
2012	Dynamic Routing and wavelength Assignment with Backward Reservation in wavelength -routed Multifiber WDM Networks	Dewiani, Kouji Hirata, Khamisi Kalegele, Yoshinobu Higami, Shin-ya Kobayashi.	The author introduced the new Dynamic RWA scheme with signalling the backward reservation for multiber WDM network
2012	Benefits of Implementing a Dynamic Impairment-Aware Optical Network: Results of EU Project DICONET	Marianna Angelou, Siamak Azodolmolky, Loannis Tomkos, Jordi Perello, Salvatore Spadaro, Davide Careglio, Kostas Manousakis, Panagiotis Kokkinos, Emmanouel.	The author stated the key features of the DICONET solution by showing some of the achievement of the project.

2012	An impairments aware tool for planning and managing dynamic optical networks	Azodolmolky. S, Kokkinos. P, Angelou. M, Varvarigos E, and Tomkos	The author have presented the planning and major building blocks of DICONET NPOT

2.3 Review of Dynamic impairments

[Rahbar et al. 2010] states that Quality of transmission aware routing and wavelength assignment technique are appropriate for multi-fiber wavelength routed all optical networks which support the class based light-paths; the evaluation of QoT is done not only for candidate light-path setup but also for the already existing light-paths. In this paper the author has proposed four techniques for improvement of the performance: (1) Replacing the low-quality light-path with high quality with bandwidth usage in giving better Quality of Service (QoS) for high quality traffic. (2) Class based buffering. (3) Low quality light-paths routed through large dispersion paths and vice versa. (4) Wavelength ordering to reduce crosstalk.

The author did not refer to any previous work.

The main objectives of the paper [Rahbar et al. 2010] are create an edge architecture for saving the requests and establish when possible, Should be able to manage high quality and low quality light-paths in the optical domain, change the low quality light-path considering the bandwidth to accommodate the high quality connections, use the wavelength order in reducing the crosstalk effects in switches and fibers, routing the low quality light-paths through the large dispersion paths and vice versa, should design a QoT-aware RWA which is suitable for class-based light-paths which takes into account the physical layer impairments in a multi-fiber network. As the algorithm supports both QoT and QoS it is called as QoTS.

The network topology without wavelength conversion is used to evaluate the performance of the QoTS RWA. In a dynamic traffic model, the connection requests are arrived at network based on Poisson process taking the arrival rate of A in the total network and the mean connection with H time units (H with a mean of 5min).The traffic load arrives with Erland. Between the pair of ingress and egress there are 8 alternate routes are used by ALD routing. The parameters wavelength range, frequency, channel bit rate, optical bandwidth, electrical bandwidth, switch crosstalk ratio, loss of a multiplexer and de-multiplexer unit, loss of switch and tap, gain of EDFA in switch, fiber effective area, source power per wavelength and ASE factor of EDFA in a switch are considered for carrying the experiment. The experiment is included with blocking probability, pre-emption of low quality light-paths and setup time.

The worst care network topology is been evaluated for calculating the long distance between the two adjacent nodes. As the network works in a distributed manner in computing the OSNR values of candidate light-path and present

light-paths, most of the setup time is for delay in propagation because of the evaluation of the OSNR on present light-paths. The multi-fiber network with f=2 fiber will be the nest choice which gives the trade-off between blocking and setup time. By relieving the OSNR computation with evaluation of the OSNR for the candidate light-paths we can have smaller setup time.

[Rahbar et al. 2010] claims that even if the OSNR evaluation leads to high computation and will increase the blocking and setup time, the long-haul optical network is necessary as ideal physical consideration is a reasonable assumption.

Year	Title	Authors	Major Contribution
2010	Dynamic Impairment-Aware RWA in Mutifiber Wavelength-Routed All Optical Networks Supporting Class-Based Traffic	Akbar Ghaffar Pour Rahbar	In this paper the author has proposed four techniques for improvement of the performance for QoT.

3. CONCLUDING COMMENTS

This survey gives a rundown on the topic Impairment aware dynamic routing and wavelength assignment. Relevant research papers were found by searching Google Scholar with the keywords Impairment aware routing and wavelength assignment, Online RWA, etc. The keywords and author names were used to search the ACM publication library, IEEE and LNCS. The total of 10 papers was selected in this survey. This survey contains 7 journal papers, 3 conference papers, etc. which are closely related to this survey were identied. With this survey i gained much more knowledge on my topic. In doing this survey i have noticed that this topic has gained lot of popularity and many researches is been still going on since years.

Year	Authors	Title	Papers refered to
2008	Yogmin Qi, Yi Zhu, Tianshu Wang, Xuefang Zhou, Sheng Qian and Qiliang Li.	Impairment -Aware Dynamic RWA algorithm in Multi-Granularity WDM Optical Networks	Qi et al. 2006
2009	Stephan Pachnicke, Nicolas Luck, Peter M. Krummrich	Online Physical-Layer Impairment-Aware Routing with Quality of Transmission Constraints in Translucent Optical Networks	NONE
2010	K.Potou, K.Manousakis, K. Christodoulopou-los, E. Varvarigos	Dynamic Routing and Wavelength Assignment in Transparent WDM Networks with Amplifiers' Power Constraints	NONE
2010	Akbar Ghaffar Pour Rahbar	Dynamic Impairment-Aware RWA in Mutifiber Wavelength-Routed All Optical Networks Supporting Class-Based Traffic	NONE
2011	Konstantinos christodoulopoulos, Panagiotis Kokkino and Emmanouel Manos Varvarigos	Indirect and Direct Multicost Algorithm for Online Impairments-Aware RWA	NONE

2011	Davide Adami, Stefano Giordano, Michele Pagano, and Luiz Gustavo Zuliani	Indirect and Direct Multicost Algorithm for Online Impairments-Aware RWA	NONE
2012	Kouji Hirata and Dewiani	Online Lightpath Provisioning and Critical Services: New IA-RWA Algorithms to Assure QoT and Survivability	NONE
2012	Dewiani, Kouji Hirata, Khamisi Kalegele, Yoshinobu Higami, Shin-ya Kobayashi.	Online Lightpath Provisioning and Critical Services: New IA-RWA Algorithms to Assure QoT and Survivability	NONE
2012	Marianna Angelou, Siamak Azodolmolky, Loannis Tomkos, Jordi Perello, Salvatore Spadaro, Davide Careglio, Kostas Manousakis, Panagiotis Kokkinos, Emmanouel.	Dynamic Routing and Wavelength Assignment in Multifiber WDM Networks with wavelength Conversion Capability	Rahbar. 2010
2012	Azodolmolky. S, Kokkinos. P, Angelou. M, Varvarigos E, and Tomkos	Dynamic Routing and wavelength Assignment with Backward Reservation in wavelength -routed Multifiber WDM Networks	Rahbar. 2010

4. ACKNOWLEDGEMENT

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5. ANNOTATIONS

5.1 *Citation:* Adami, D., Giordano, S., Pagano, M., and Zuliani, L. 2011. On-line lightpath provisioning and critical services: New IA-RWA algorithms to assure qot and survivability. *In High Performance Switching and Routing (HPSR), 2011 IEEE 12th International Conference on* (2011), IEEE, pp. 101106.

The problem which the researchers/authors addressed: The author states that the Wavelength Routed Photonic Networks are imperfect in adapting the classic Routing and Wavelength assignment solutions .And the author address the issues like physical impairments and Quality of transmission, process and delay time, Lightpath constancy and Minimum resource allocation ,the solutions of the Routing and Wavelength Assignment are not sufficient to be used by Wavelength Routed Photonic Networks (WRPNs), these networks would play an important role in future internet applications. Even in network failure QoT should be guaranteed in lightpath transmission.

Previous work by others referred to by the authors: The author do not refer to any previous work.

Shortcomings of previous work: Author has proposed an algorithm in his previous work Adami et al. [2010] without considering the resilience.

The new idea, algorithm, architecture, protocol, etc.: In this paper the authors have come up with two new algorithms to support the critical services in Wavelength Routed Photonic Networks. The main objectives of these two algorithms are to protect with assured QoT and to minimize the resource allocation. The first algorithm uses on-the-fly multipath RWA with calculation referred by Dijkstra Algorithm and the second algorithm uses Suurballe algorithm. The results are compared with IA-RWA survivable algorithm Markidis et al. [2009]. The authors stated that this algorithms strictly provides either 1+1 or 1:1 protection. The single cut fiber cut and critical services of WRPNs are designed with redundant hardware. The main aim of these algorithms is to guarantee QoT and survivability in single link failure case, the complexity of these algorithms is lower and setu delay of the lightpath is reduced. These algorithms named MCP- D^2 and MCP-S, inherit the main features of MCP-RWA algorithm and improve the survivability support. MCP- D^2 will calculate the primary and the secondary lightpaths by applying the MCP-RWA algorithm twice. Once for the original topology and then residual network to primary lightpath after all

links are cut short. In MCP-S, they use suurballe algorithm in calculating a pair of disjoint lightpaths on available wavelength. By using the two disjoint lightpaths of same wavelength decreases blocking in future by removing trap topology problem and my decreasing the wavelength fragmentation.

Experiments and/or analysis conducted: The proposed algorithms performances was evaluated by comparing with $(D+FFWO)^2$. Firstly the primary lightpath was computed using Dijkstra algorithm. Then a wavelength was assigned for a primary lightpath using FFwO heuristic and then QoT was evaluated. Then the links of the primary lightpaths were cut short from the topology. And then the backup lightpath is computed and impairments are validated by repeating the same process used in the first phase.

Results that the authors claim to have achieved: When there are less number of connection requests, $(D+FFWO)^2$ will have the lowest processing time irrelevant of the network. The new algorithm decreases when there is increase in number of connection request. This is done due to the IA-RWA process of MCP- D^2 and MCP-S which remove the unusable WG. It is important that to highlight the processing time required in computing the path is just fraction of overall light-path setup time, which includes signalling and configuration time. Hence MCP-D2 is the best choice as it ensures lowest blocking probability and higher processing time.

Claims made by the authors: The authors state that the algorithm achieves the better blocking probability, and requires less processing time. Hence the algorithm is designed to give absolute QoT and hundred percentage survivability even in the single failure and to minimize the resource allocation. The chances of blocking the future requests and in reducing the setup delay. This was achieved by combining the high parallelizable multipath IA-RWA procedure with simple and effective heuristics.

5.2 *Citation:* Angelou, M., Azodolmolky, S., Tomkos, I., Perelló, J., Spadaro, S., Careglio, D., Manousakis, K., Kokkinos, P., Varvarigos, E., Staessens, D., et al. Benefits of implementing a dynamic impairment- aware optical network: results of eu project diconet. *Communications Magazine, IEEE 50*, 8 (2012), 7988.

The problem which the researchers/authors addressed: The author states that network design and the operation are the major impact in optical transparency. In order to deal with physical-layer effects that's degrades the Quality of transmission (QoT) a European DICONET was addressed to meet these challenges. In this paper the author have proposed and came up with good solution which smoothens transmission.

Previous work by others referred to by the authors: The author referred to previous work Christodoulopoulos et al. [2011]

Shortcomings of previous work identified by the authors: No shortcoming of the previous work.

The new idea, algorithm, architecture, protocol, etc : The author stated the key features of the DICONET solution by showing some of the achievement of the project. In DICONET a set of cross layer optimization algorithms are designed in order to serve the network while planning and operation. These algorithms are combined in one software platform where the DICONET NPOT considers the impacts of physical layer impairments. The DICONET network solution is effectively supported by control plane in developing the generalised multiprotocol switching and allowing to the different entities run in the orchestrated manner. The completion of the project was done with implementing the multilevel integrated solution in DICONET testbed and practically realizing the vision for an end to end connectivity, dynamicity and reliability.

Experiments and/or analysis conducted: The testbed was used for experiment and test the performance of two architectures with respect to lightpath to and fro dynamically. The distributed scheme outputs the lower setup times in high dynamic traffic condition with the benefit from parallel establishment of lightpath. The better blocking ration is justified by impairment aware routing process in centralised scheme. This centralised scheme allows the routing engine to have a complete view of the physical layer and the condition of traffic. But only one connection request can be served at one time, hence increasing the setup time. And strategy is implemented to improve the setup time of the lightpath for centralized scheme.

Results that the authors claim to have achieved: With the dynamicity offered by integrated solution the DICONET will properly react to the failure and restoring the traffic which is affected in transparent fashion. To evaluate these things the centralised configuration is done where the failures occur randomly in the network. A set of predefined active paths were loaded in the network and by randomly eliminating the link cuts the independent failures. The result indicated as the fast restoration times even though there was sequential processing of lightpaths. Finally the result showed that in less than 5s the 72 percent of lightpath were restored.

Claims made by the authors: The author claims that in order to achieve the resource optimization in future flexible networks more investigation should be done in the issues like signal evaluation with advanced transmission parameters and allocation of dynamic bandwidth.

5.3 *Citation:* Azodolmolky, S., Kokkinos, P., Angelou, M., Varvarigos, E., and Tomkos, I. Diconet npot: An impairments aware tool for planning and managing dynamic optical networks. *Journal of Network and Systems Management* (2012), 118.

The problem which the researchers/authors addressed: The main problem the author addressed is the quality of the signal degrades as it propagates due to various types of distortions. Hence the DICONET project was introduced, the main aim of DICONET is to design and develop a physical layer impairment-aware Network planning and Operation Tool that link the performance of optical

layer to IA-RWA, placement of the components and the algorithms which handle the failure.

Previous work by others referred to by the authors: The author did not refer to any previous work.

Shortcomings of previous work identified by the authors: No shortcoming of the previous work.

The new idea, algorithm, architecture, protocol, etc.: The author have presented the planning and major building blocks of DICONET NPOT. And also briefly explained the schemes that accommodate NPOT into the IA- GMPLS based control planes. The integration part was explained considering two approaches namely Centralized and Distributed Approach. In the centralized approach IA-RWA and the failure management are been carried out while the OCCs executes the GMPLS protocols and blend to the main optical nodes. In distributed approach both RSVP-TE and OSPF-TE protocols were bound to allow the impact of PLIs with many understandings between network performance, control overhead and the complexity. The wavelength availability information is distributed by extending the OSPF-TE protocol. Each node is considered as an instance of NPOT which is connected to OCC through NPOT-OCC protocol. New connection request, to compute the k-shortest path, the source not request the online IA-RWA module of NPOT.

Experiments and/or analysis conducted: The author have selected Deutsche Telekom's national network for carrying out the experiments. DTNet has 14 nodes and 23 bidirectional links, node degree of 3.29 and length of the link 186KM average. No light-path longer than 1500km and agreeable QoT, without taking the impact of present light-paths. The NPOT in planning mode is evaluated with the ratio of number of light-paths demands and number of pairs of nodes.

Results that the authors claim to have achieved: The performance results gather from planning and operation modes of DICONET NPOT were presented by the author. In NPOT planning all the demands were served with any blockage for every load values. The Rahyab module requests Q-tool to check the performance of each light-path to provide the minimum QoT on current light-path. Hence the computation time is high on NPOT. Where as in Operation mode when there is more connections request the ration of success in connection decreases though there are many channels available. The execution time of MP algorithm increases due to more available channels. Before the new light-path is established the Q-factor value of all the light-paths has to be calculated which intern result increasing the total execution time.

Claims made by the authors: Author claims that the main contribution of the DICONET project is designing and development of a network with PLIs aware planning and operation tool. NPOT exist in core network nodes including the physical layer's performance when planning and operation.

5.4 *Citation:* Christodoulopoulos, K., Kokkinos, P., and Varvarigos, E. Indirect and direct multicost algorithms for online impairment-aware rwa. *Networking, IEEE/ACM Transactions on 19*, 6 (2011), 1759 1772.

The problem which the researchers/authors addressed: The author states that due to the physical layer impairments the quality of the signal degrades, the algorithms should also carry out to serve a new connection, find a route and free the wavelength. And also due to the effect of interference the light will affect and get affected by the other light-path while establishing the new light-path.

Previous work by others referred to by the authors: The author did not refer to any previous work.

Shortcomings of previous work identified by the authors: No shortcoming of the previous work.

The new idea, algorithm, architecture, protocol, etc.: The author has come up with two multicost algorithms which stand as a solution for interference effects, physical effects, a cross layer optimization between network and physical layer. The first algorithm evaluates the quality of the candidate light-path with combination of scalar paths, uses the cost vectors with impairment creating source parameters which would be applicable for physical settings. In second algorithm the physical models are used to define noise variance which is related with the cost parameters for calculating the Q-factor of the candidate light-path. These algorithms will find the set of non-dominated paths which help the connection thinking that no other path is better in the set reference to cost parameters.

Experiments and/or analysis conducted: Author have used MATLAB in carrying out the simulation experiments for evaluating the performance of the algorithms. A transparent candidate network recognised by DICONET project, Generic DT network topology simulations were performed. The detailed analytical models used but Q-factor estimator for evaluating the feasibility of selected light-path. The unacceptable QoT is known by calculating the Q-factor with the help of Q-Tool taking the input as new and presently established light-paths. The request connection for a single wavelength is produced with respect to a Poisson process with rate λ request/time. The source destination is uniformly chosen from among all nodes. Also the authors carried out the experiments on tuning the parameters of the Multi-Parametric Algorithm, in comparing the performance of the Multicost Algorithms and random networks experiments.

Results that the authors claim to have achieved: The experiments were carried out for evaluating the scalability of the IA-RWA algorithms. 10 Random networks with 40 networks in total were created and connectivity degree is 3.5. For every network the number of hops of the longest path should be found and a distance should be set between two adjacent nodes which is 1200KM. The author have represented in result graphically which states that blocking probability and the running time for feeding a single connection, average of 10 random

networks for each value of N. The blocking probability decreases as the number of nodes increases as the same load is divided with the larger network and the congestion link is low. With that of the MP algorithm the SC algorithm exhibits the best blocking performance. With the node of node the average running time increases.

Claims made by the authors: The author claims that these algorithms can efficiently assist the online traffic in transparent network with guaranteeing the quality of transmission of light-path with as low running times.

5.5 *Citation:* Hirata, K., et al. Dynamic routing and wavelength assignment in multiber wdm networks with wavelength conversion capability. *Network and Communication Technologies* 1, 2 (2012), p36.

The problem which the researchers/authors addressed: The author states that in multifiber WDM network every link is with multiple fibers. Hence we can establish multiple light-paths with the with same wavelength in the same link only possible in different fiber. A scheme was needed to efficiently use the multifiber and wavelength conversion. The author have proposed an new scheme for it.

Previous work by others referred to by the authors: The author referred to previous work Rahbar. [2010].

Shortcomings of previous work identified by the authors: No shortcoming of the previous work.

The new idea, algorithm, architecture, protocol, etc. The author has proposed a new scheme which is capable for providing the RWA for multifiber WDM networks with sparse and highly capable for full wavelength conversion. Based on the wavelength availability and the location of the node with capability of wavelength conversion, a route and wavelength are selected for every light-path. A path which does not share a same link and a wavelength is selected from the pre-defined routes between sender and receiver node. Then each path is divided into segments between nodes with wavelength conversion. The generation of bottleneck links and need of the specific wavelength is avoided by selecting the route from predefined paths and assigns the wavelength for a selected path.

Experiments and/or analysis conducted: The scheme will select a path from a set of predefined link disjoint paths. And to create those predefined paths, an algorithm will be adopted for every pair of sender and receiver node. Firstly using Dijkstra's algorithm, scheme finds the shortest path from the source to destination, and opt the path as a link disjoint path. The scheme will now find a new shortest path on a graph and a path is opted as a new link disjoint path. Till there are routes from the source to destination this process is repeated.

Results that the authors claim to have achieved: In order to evaluate the scheme the author has conducted simulation experiments with the network

topology. They have taken a network with 24 nodes and 43 bidirectional links, and with N wavelength conversion. Suppose the value of N is 24, full wavelength conversion capability is present in the network. For low complexity a propagation delay of every link is 0.1 and the processing time is 0.01. The author calculated the simulation results of the spare wavelength conversion, full wavelength conversion network and with no wavelength conversion network.

Claims made by the authors: The author claims this scheme work great in networks with and without full capability of wavelength conversion, and that they have showed the robustness of the scheme with wavelength at each fiber, number of fibers at each link etc. In future author claims that they will consider the physical layer impairments.

5.6 *Citation:* Hirata, K., Kalegele, K., Higami, Y., Kobayashi, S., et al. Dynamic routing and wavelength assignment with backward reservation in wavelength-routed multiber wdm networks. *Journal of Networks* 7, 9 (2012), 14411448.

The problem which the researchers/authors addressed: The author states that due to the coarse granularity and wavelength continuity constraint for establishment of light-path the probability of blocking is very high in wavelength routed WDM network. This is very much critical issue which must be resolved. This could be reduced by introducing, multifiber where each link consists of multiple fiber, and by better RWA algorithm. The author in this paper proposed an RWA algorithm.

Previous work by others referred to by the authors: The author refers the previous work of Rahbar. [2010].

Shortcomings of previous work identified by the authors:

The new idea, algorithm, architecture, protocol, etc.: The author came up with the new Dynamic RWA scheme with signalling the backward reservation for multifiber WDM network. In this scheme when the request for the new light-path arrives the collection of information is done between the source node and the destination node, by signalling backward reservation along multiple routes. Now the scheme will select a mixture of route and wavelength at the destination node with the help of information collected where the bottleneck links and the need of a specific wavelength can be avoided. This scheme helps in reducing the blocking probability in establishing the light-path.

Experiments and/or analysis conducted: The experiments were carried out in constructing the predefined paths, information collecting by signalling and selection of Route and wavelength. In constructing the predefined paths the simple algorithm is used where firstly a shortest path is found from source to destination with dijkstra's algorithm. And link is removed along the path from graph this process will be repeated till there are no routes from source to destination. In collecting the information, whenever the new light-path request raises PROB message is sent from sender node to receiver. The receiver will wait till it gets all PROB messages, then based on the information collected

by PROB messages the receiver node will select a route and wavelength. Then the receiver will send the RESV message to sender from the selected route in eastablishing the light-path with selected wavelength. In route and wavelength selection the combination with low cost is selected by receiver node. The new light-path establishment is blocked if the cost is infinity. The scheme selects the shorter hops if there are more than two combinations with minimum cost.

Results that the authors claim to have achieved: The blocking probability of establishment of light-path as a function offered load is represented in a form of graph. The blocking probability of light-path establishment is stated as a ratio of number of blocked light-path setup request and the total number if lightpath setup request. The blocking probability of SR is quite high as the wavelength availability in the network and bottleneck links are not considered. This scheme reduces the blocking probability as it effectively uses wavelength resources. It selects a combination from more candidates and wavelength resources are efficiently used by proposed cost function.

Claims made by the authors: The author claims that this scheme avoids the generation of bottleneck links and need of that a wavelength.

5.7 *Citation:* Pachnicke, S., Luck, N., and Krummrich, P. 2009. Online physical-layer impairment-aware routing with quality of transmission constraints in translucent optical networks. In *Transparent Optical Networks, 2009. ICTON'09. 11th International Conference on* (2009), IEEE, pp. 14.

The problem which the researchers/authors addressed: The authors address the problem that quality of transmission (QoT) goes down with the network load and change of channel. In large dimensional translucent optical networks (pan-European Networks) the quality of the signal is very important in transparent paths. Due to the high cost of 3R regenerations, limited regeneration sites are deployed.

Previous work by others referred to by the authors: The authors do not refer to any previous work.

Shortcomings of previous work: No shortcoming of the previous work.

The new idea, algorithm, architecture, protocol, etc.: The authors present a novel online constraint-based routing (CBR) algorithm using the present channel load in properly modeling the inter channel effects, guarantee connection and will give the minimum signal quality when new connection is established. This CBR algorithm considers linear and Non-linear impairments.

Experiments and/or analysis conducted: In Mesh topology, the authors have chosen COST266 European core network with 28 nodes and 42 bidirectional edges. No physical parameters are assigned hence span lengths are selected by heuristic approach with the assumptions by networks in generating the replacements for the missing data. A dispersion pre-compensating with -650 ps/nm was deployed. Author assumed that the polarization mode dispersion values

in the forward and backward would be same as the fibers were from the same cable with similar properties. A channel plan with a highest of 40 wavelength per link were placed with 50GHz. The EDFA was set, a noise figure value was assumed. And stated the minimum Q-factor was required in the study.

Results that the authors claim to have achieved: The author presents their results using graphs. Author compares CBR algorithm to a commonly used shortest path routing with high transparent reach. The result shows that nearly 3000km was need to get the same performance. Shorter transparent reach results high blocking probability. For a assumed simulation there are good communication in long pat and bad quality in short path. Finally, the result show that shortest path routing will results to high blocking probability compared to offline and online CBR algorithms.

Claims made by the authors: The Authors claim to have undertaken a new study of a new online constraint based routing (CBR) algorithm considering the QoT. This algorithm gives the accurate assessment for the nonlinear degradation effects by considering the present network load. The authors states that they algorithm is superior to the shortest path routing and also outruns a CBR algorithm in worst case transmission.

5.8 *Citation:* Potou, K., Manousakis, K., Christodoulopoulos, K., and Varvarigos, E. Dynamic routing and wavelength assignment in transparent wdm networks with ampliers' power constraints. *In Future Network and Mobile Summit,* 2010 (2010), IEEE, pp. 18.

The problem which the researchers/authors addressed: The author states that the signal quality degrades as it propagates through the network in the wavelength routed optical network

Previous work by others referred to by the authors: The author did not refer to any previous work.

Shortcomings of previous work identified by the authors: No shortcoming of the previous work.

The new idea, algorithm, architecture, protocol, etc: The author presented an extension of multicost impairment aware online algorithm to include amplifier power constraints. This extended algorithm covers possible saturation of amplifers that changes when a new connection is established in the link. In terms of blocking probability and rerouting frequency this extended algorithm preforms better compared to that of previous proposed algorithm.

Experiments and/or analysis conducted: The performance of the algorithm is evaluated with power constraints algorithms in matlab. The Q-factor of the new and established light-path is calculated by using Q-factor estimator tools and determines the unacceptable transmission quality. The optimum light-path is chosen by using Q policy. The algorithm has two phases, before the first phase the cost parameters are given and the cost vector is created by

calculating the amplifier gain and noise variance. In the first phase a set of non-dominated Q paths are found from the source node to other all nodes in the network. The path which is dominated by the other path has the least delay, availability of wavelength and QoT than another path, and if there is no further extension there will be no path. In this way the algorithm will have at least one wavelength available and that wavelength will have the least acceptance of Q-factor performance. In the second phase the optimum solution is found by applying the optimization function to the cost vector. In order to choose the optimal lightpath for a connection various objective functions evaluated and proposed. To have a procedure of rerouting, it has to check the amplifier gain for variations as QoT of the other already established lightpath may be unacceptable.

Results that the authors claim to have achieved: The author states that the rerouting for the IA-RWA with the power constraints are relatively small so the execution time of the algorithm with and without rerouting is almost similar. And even the two algorithms for rerouting and available 50 wavelengths have same execution time. As IA-RWA algorithm performs many reroutings and while IA-RWA with power constraints performs a less number of reroutings and need more time to evaluate the gain of amplifiers.

Claims made by the authors: The author claims that the total output gain of the amplifier is saturated as to higher the input signal power which uses the wavelengths. The algorithms can lower the blocking probability for a new connection and for already established connection it lowers the rerouting probability.

5.9 *Citation:* Qi, Y., Zhu, Y., Wang, T., Zhou, X., Qian, S., and Li, Q. 2008. Impairment-aware dynamic rwa algorithm in multi-granularity wdm optical networks. In *Proc. of SPIE* Vol (2008), *vol.* 7137, pp. 71373D 1.

The problem which the researchers/authors addressed: The author addresses the issue regarding the transmission of the optical signal. The Optical signal will be degraded due to impairments mainly because of the number of multi-granularity optical cross-connects and the fiber links. These impairments cause a bit-error rate which is unacceptable.

Previous work by others referred to by the authors: The authors refer to the previous work Qi et al. [2006].

Shortcomings of previous work: No shortcoming of the previous work.

The new idea, algorithm, architecture, protocol, etc.: The authors has presented a model to study the impacts in transmission impairment on the quality of signal in multi granularity optical WDM networks. The losses of optical signal are due to the fiber/waveband/wavelength switches, multiplexers, demultiplexers and fiber links. A novel dynamic transmission impairment-aware RWA heuristic algorithm is proposed based transmission impairment model.

This RWA algorithm takes the effects of transmission impairment when a multi granularity LP was setup to carryout waveband routing in network layer.

Experiments and/or analysis conducted: MNWR-TIA algorithm in the network topology for the dynamic traffic demand it represented in a diagram. Based on the MNWR-TIA algorithm both serial MG-OXCs and interconnecting MG-OXCs were simulated. The poisson distribution for an incoming request was assumed and with a negative exponential distribution the connection request limitation was satisfied. And for more simulation of the equation author referred to Qi et al. 2006.

Results that the authors claim to have achieved: The blocking probability for both the MG-OXCs network was increased while the network traffic load was increasing. The interconnecting MG-OXCs acquire better blocking act which was benefited from integrity and flexibility for the interconnecting architecture compared with serial cascaded MG-OXCs.

Claims made by the authors: The authors claim that the MNWR-TIA algorithm can support guaranteed signal quality lightpath in WDM networks and the interconnecting MG-OXCs network has a very low blocking probability compared to that of serial cascaded MG-OXCs.

5.10 *Citation:* Rahbar, A. Review of dynamic impairment-aware routing and wavelength assignment techniques in all-optical wavelength-routed networks.

The problem which the researchers/authors addressed: The author states that Quality of transmission aware routing and wavelength assignment technique are appropriate for multifiber wavelength routed all optical networks which support the class based lightpaths, the evaluation of QoT is done not only for candidate lightpath setup but also for the already existing lightpaths. In this paper the author has proposed four techniques for improvement of the performance: (1) Replacing the low-quality lightpath with high quality with bandwidth usage in giving better Quality of Service (QoS) for high quality traffic. (2) Class based buffering. (3) Low quality lightpaths routed through large dispersion paths and vice versa. (4) Wavelength ordering to reduce crosstalk.

Previous work by others referred to by the authors: The author did not refer to any previous work.

Shortcomings of previous work identified by the authors: No shortcoming of the previous work.

The new idea, algorithm, architecture, protocol, etc: The main objectives of the paper are create an edge architecture for saving the requests and establish when possible, Should be able to manage high quality and low quality lightpaths in the optical domain, change the low quality lightpath considering the bandwidth to accommodate the high quality connections, use the wavelength ordering in reducing the crosstalk effects in switchs and fibers, routing the low quality lightpaths through the large dispersion paths and vice versa, should design a QoT-aware RWA which is suitable for class-based lightpaths which takes

into account the physical layer impairments in a multifiber network. As the algorithm supports both QoT and QoS it is called as QoTS.

Experiments and/or analysis conducted: The network topology without wavelength conversion is used to evaluate the performance of the QoTS RWA. In a dynamic traffic model, the connection request are arrived at network based on Poisson process taking the arrival rate of A in the total network and the mean connection with H time units (H with a mean of 5min).The traffic load arrives with Erland. Between the pair of ingress and egress there are 8 alternate routes are used by ALD routing. The parameters wavelength range, frequency, channel bit rate, optical bandwidth, electrical bandwidth, switch crosstalk ratio, loss of a multiplexer and demultiplexer unit, loss of switch and tap, gain of EDFA in switch, fiber effective area, source power per wavelength and ASEfactor of EDFA in a switch are considered for carrying the experiment. The experiment is included with blocking probability, preemtion of low quality lightpaths and setup time.

Results that the authors claim to have achieved: The worst care network topology is been evaluated for calculating the long distance between the two adjacent nodes. As the network works in a distributed manner in computing the OSNR values of candidate lightpath and present lightpaths, most of the setup time is for delay in propagation because of the evaluation of the OSNR on present lightpaths. The multifiber network with f=2 fiber will be the nest choice which gives the trade-off between blocking and setup time. By relieving the OSNR computation with evaluation of the OSNR for the candidate lightpaths we can have smaller setup time.

Claims made by the authors: The author claims that even if the OSNR evaluation leads to high computation and will increase the blocking and setup time, the long-haul optical network is necessary as ideal physical consideration is a reasonable assumption.

References

[1] Adami, D., Giordano, S., Pagano, M., and Zuliani, L. Online lightpath provisioning and critical services: New ia-rwa algorithms to assure qot and survivability. In *High Performance Switching and Routing (HPSR), 2011 IEEE 12th International Conference on* (2011), IEEE, pp. 101–106.

[2] Angelou, M., Azodolmolky, S., Tomkos, I., Perelló, J., Spadaro, S., Careglio, D., Manousakis, K., Kokkinos, P., Varvarigos, E., Staessens, D., et al. Benefits of implementing a dynamic impairment-aware optical network: results of eu project diconet. *Communications Magazine, IEEE 50*, 8 (2012), 79–88.

[3] Azodolmolky, S., Kokkinos, P., Angelou, M., Varvarigos, E., and Tomkos, I. Diconet npot: An impairments aware tool for planning

and managing dynamic optical networks. *Journal of Network and Systems Management* (2012), 1–18.

[4] Christodoulopoulos, K., Kokkinos, P., and Varvarigos, E. Indirect and direct multicost algorithms for online impairment-aware rwa. *Networking, IEEE/ACM Transactions on 19*, 6 (2011), 1759–1772.

[5] Hirata, K., et al. Dynamic routing and wavelength assignment in multifiber wdm networks with wavelength conversion capability. *Network and Communication Technologies 1*, 2 (2012), p36.

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[7] Pachnicke, S., Luck, N., and Krummrich, P. Online physical-layer impairment-aware routing with quality of transmission constraints in translucent optical networks. In *Transparent Optical Networks, 2009. ICTON'09. 11th International Conference on* (2009), IEEE, pp. 1–4.

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[10] Rahbar, A. Dynamic impairment-aware rwa in multifiber wavelength-routed all-optical networks supporting class-based traffic. *Optical Communications and Networking, IEEE/OSA Journal of 2*, 11 (2010), 915–927.