Physical Layer Impairments Aware Data-Path Selection (PLIADS) in WDM Network

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***Abstract*— In optical networks, physical layer impairments (PLIs) incurred by non-ideal optical transmission media, accumulates along the optical path. The overall effect of PLIs determines the feasibility of the light-paths. It is important to understand the process that provide PLI information to the control plane protocols and use this information efficiently to compute feasible routes and wavelengths. Based on the PLI impairments like power loss, chromatic dispersion, capacity of the channel with reflects the bandwidth and Quality of service factors; it is proposed to a centralized PLI based routing algorithm for the selection of data-paths.**

***Index Terms*— Link-capacity, Physical layer Impairments, Q-factor, Light-path, Power loss, Data-path.**

I. INTRODUCTION

Day to day growth in telecommunication network requires functionalities like dynamic data-path selection with guaranteed Quality of service (QoS) [1, 2], which are essential for any optical network. Data-path selection of the WDM network depends on the physical as well as IP layer information. The degradation of data-path may happen due to Physical layer impairments (PLI). PLIs are broadly classified in to two categories: linear and non-linear impairments [3, 4, 5 6]. The terms linear and non-linear in fiber optics mean intensity-independent and intensity-dependent, respectively. The linear impairments are static in nature and non-linear impairments are dynamic in nature. The non-linear impairments strongly depend on the current allocation of route and wavelength, i.e., on the current status of allocated light paths

In this paper, we focus on PLI Impairments, which are defined as the parameter effect in the physical layer while establishing the connection between source nodes to destination node. The main objectives of this paper is to when and how to select a data-path.

II. PROBLEM FORMULATION

We consider a topology, where a number of flows from the client source to client destination. The flows are to be aggregated at the source node. We consider a capacity and PLI based model based on client traffic requirement and existing traffic in the following section.

A. Bandwidth Model

Suppose a flow for client *m* and *n with* data-path from source *s* to destination *d.* For every edge router, a free available capacity matrix, $_1$ has been considered, where *s* and *d* are the source and destination edge GPRs for a DP.

If *D (i, j)* is the dispersion of the fiber at the operating wavelength with unit's seconds per nano meter per kilometer, and *L (i, j)* is the length of fiber link pair *(i, j)* in kilometers, then the capacity matrix $C(m,n,s,d)$ can be explained [7] as follows:

$$C(m,n,s,d) = \sum_{(i,j)\in p(m,n,s,d)} \frac{\delta}{D(i,j)\times L(i,j)} \tag{1}$$

where, δ represents the pulse broadening factor should typically be less than 10% of a bit's time slot for which the polarization mode dispersion (PMD) can be tolerated [8] and *D (i, j) = L (i, j) =* ∞, when there is no link between i^{th} *and* j^{th} node.

The capacity metrics $C(m,n,s,d)$ calculation is derived from a single link to a group of links in a DP.

B. PLI Model

Assume a flow for client *m* and *n with* DP from source *s* to destination *d* has Q-Factor requirement *QFR* (*m, n, s, d*). Then the average Q-Factor $AQF_{(m,n,s,d)}$ can be expressed as follows:

$$AQF_{(m,n,s,d)} = \frac{\sum_{m=1}^{M_i} QFR\,(m,n,s,d)}{M} \tag{2}$$

Where, *M* is the total number of clients for source *i* and destination *j.*

The optical domain involves with variety of PLIs and their impact on the overall network performance. In order to get a possible DPs based on the link cost, we can consider either network layer QoS parameters such as bandwidth and delay or PLI constraints in terms of Q-Factors. Also we can consider both the cases. We consider the Q-Factor as the link cost corresponding to a light-path as mentioned in [9]. The Q-Factor (QF_i) for i^{th} link is given as below:

$$QF_i = \frac{\sum_{k=1}^{N_i} 10\log\left[Q_{i,k}^{s} / Q_{i,k}^{d}\right]}{N_k} \tag{3}$$

Where, N_k is the number of light-path at the i^{th} link, $Q_{i,k}^{s}$ and $Q_{i,k}^{d}$ are the quality factor measurements of the k^{th} light-path at the source (*s*) and destination (*d*) node of the i^{th} link respectively.

If $p(m,n,s,d)$ is the DP containing l number of links, the overall Q-Factor $QF_{overall}(p(m,n,s,d))$ will be:

$$QF_{overall}(p(m,n,s,d)) = \sum_{i}^{l} QF_i \tag{4}$$

Further according to [10],

$$\frac{Q_{i,k}^{s}}{Q_{i,k}^{d}} = \frac{1}{(\delta_{eye}(i,k)) \times (\delta_{noise}(i,k))} \tag{5}$$

Where, $\delta_{eye}(i,k)$, $\delta_{noise}(i,k)$ are the Eye penalty and Noise penalty at i^{th} and k^{th} link.

Then equation 6 becomes,

$$QF_i = \frac{\sum_{j=1}^{N_i} 10\log\left[1/(\delta_{eye}(i,k)) \times (\delta_{noise}(i,k))\right]}{N_i} \tag{6}$$

Due to amplifier spans, the channel lunch power can be relatively low without significant penalties due to noise accumulation. The eye related penalty is due to the effect of linear physical impairments such as polarization mode dispersion (PMD) and chromatic dispersion (CD), while the noise related penalty is due to the effect of amplifier spontaneous emission (ASE) and crosstalk.

$$\delta_{noise}(i,k) = \frac{P^d}{p^s} \times \frac{1}{\sqrt{F}} \tag{7}$$

Where, P^d is the outputs signal power, P^s is the input signal power and F is the noise figure and $P^d = P^s e^{-\alpha L}$, α is the attenuation constant and L is the length of the DP.

$$\delta_{eye}(i,k) = \delta_{pmd}(i,k) \times \delta_{cd}(i,k) = 102 \times C^2(i,k) \times D_p^2(i,k) \times L(i,k) \times \delta_{cd}(i,k) \tag{8}$$

Where, $C(i,k)$ is the capacity, $D_p(i,k)$ is the PMD parameter and $L(i,k)$ is the transmission length.

III. DATA PATH SELECTION MECHANISM

We have considered three different scenarios for data-path selection mechanism, such as Selection of new data-path based on a) Power loss, b) Channel capacity, and c) Q-factor of the path.

Data-path selection based on power loss: For this case we analyze the power loss for all possible paths existing in between source and destination. The data-path, which is having the minimal power loss, will be selected as the best path.

Data-path selection based on Channel capacity: The capacity matrix will be analyzed (1.1) for all possible data-paths, among all which has the highest channel capacity that can be chosen as the best path.

Data-path selection based on Q-factor: This method is the combination of both the above scenarios. For this case we analyze Q-Factor (1.3) for all possible data-paths, among all which has highest Q-factor that will be chosen as the best path.

IV. SIMULATION RESULTS AND DISCUSSION

The Figure 1 shows the basic network topology with six nodes. Here we considered three pair of source and destination nodes (1, 6), (2, 5), and (1, 3).

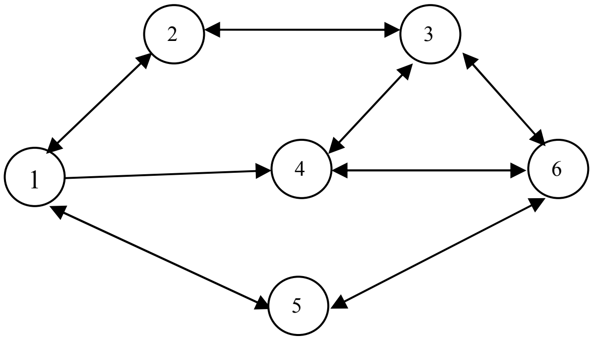

Fig. 1. Network Topology Graph

Based on our data-path selection mechanism, a best possible data-path will be chosen for a source and destinations pair. We have simulated the above topology by considering the following parameters mentioned in table1.

TABLE 1
PARAMETERS USED IN SIMULATION

Parameter	Values
Attenuation Constant(α)	0.15db
Chromatic dispersion (δ_{cd})	3000 ps
Wavelength of light (λ)	1532 nm
Noise Figure(F)	0.4db

In Figure 2, it shows the power loss for all the possible paths for a given source-destination pair, which are referred as path reference number. We have taken three different source-destination pairs such as (1, 6), (2, 5), and (1, 3), with possible paths {(1-2-36), (1-4-3-6), (1-4-6), (1-5-6)},{(2-3-6-5), (2-1-5), (2-1-4-6-5), (2-3-4-6-5)},{(1-2-3), (1-4-3), (1-5-6-3), (1-4-6-3)} respectively. The path reference number starts from 1, 2, 3, and 4 etc has been assigned to all possible paths. From the plot, it has shown that, the minimum power loss path's are (1-4-6), (2-1-5), and (1-4-3) for (1, 6), (2, 5), and (1, 3) source-destination pair respectively.

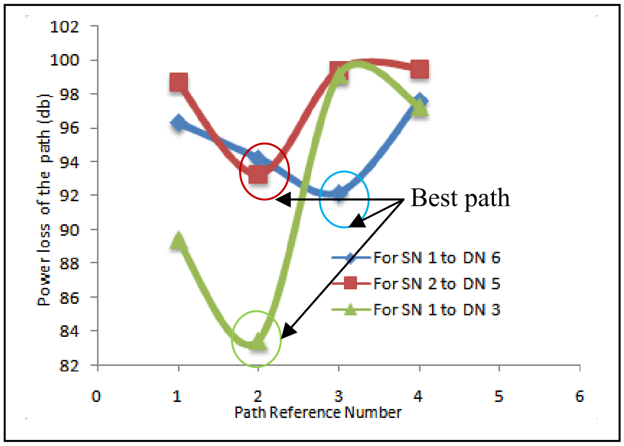

Fig. 2. Power Loss

In Figure 3, it shows the channel capacities for all the possible data-paths for the same source-destination pair as mentioned above. The plot says, the corresponding best possible paths are (1-4-3-6), (2-1-5), and (1-4-3) respectively for the given source-destination pair.

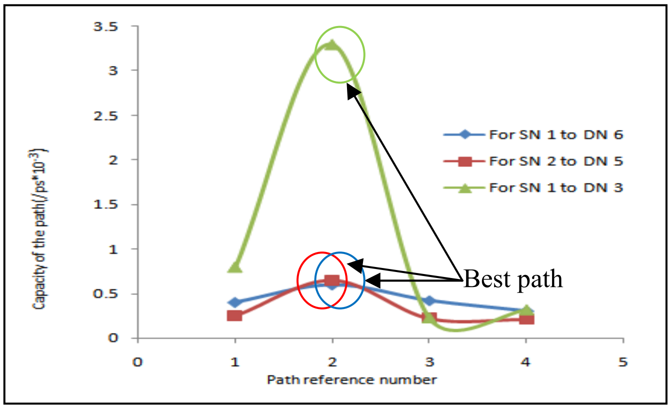

Fig. 3. Channel Capacity

In Fig. 4, it shows Q- factor for all possible paths of source and destination pair. Corresponding to the highest Q-factor values, the best path for (1, 6), (2, 5), and (1, 3) are (1-5-6), (2-1-4-6-5), and (1-5-6-3) respectively.

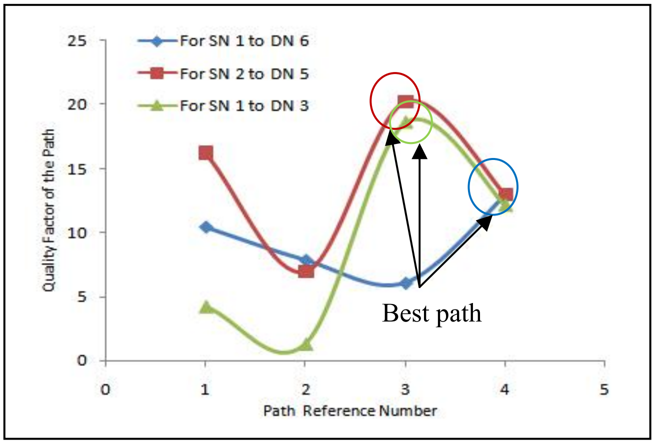

Fig. 4. Quality Factor

In Figure 5, it shows the new allotted path reference numbers to the previously assigned path reference number based on the Q-factor value. Here we considered lowest to highest of Q-factor value to assign new path reference number. For examples, in case of a source-destination pair (1, 6), the new path reference number 1 is assigned instead of the previous/old path reference number 3 which is the lowest Q-factor value ,and new path reference number 4 assigned to old path reference number 4 which is the highest Q-factor value. In general, the new path reference number is assigned based on Q-factor value in incremental order.

In Figure 6, it shows the Q-Factor for all the possible data-paths referred as the new path reference number to Q-factor. From this plot, based on Q-Factor value and clients Q-profile requirement, the best possible data-path can be selected. For example, if a client has Q-factor requirement (QF_r) of 11 for the source destination pair (1,6) , then in accordance with our algorithm, $QF_{overall}(P_i(m,n,s,d)) >= QF_r(m,n,s,d)$, i.e., 12.5 >= 11, which is approaching reference path 4 and this will be the best path.

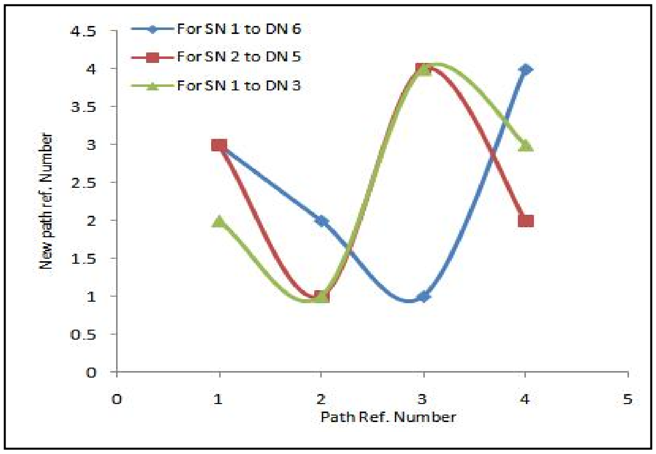

Fig. 5. New path ref. Number

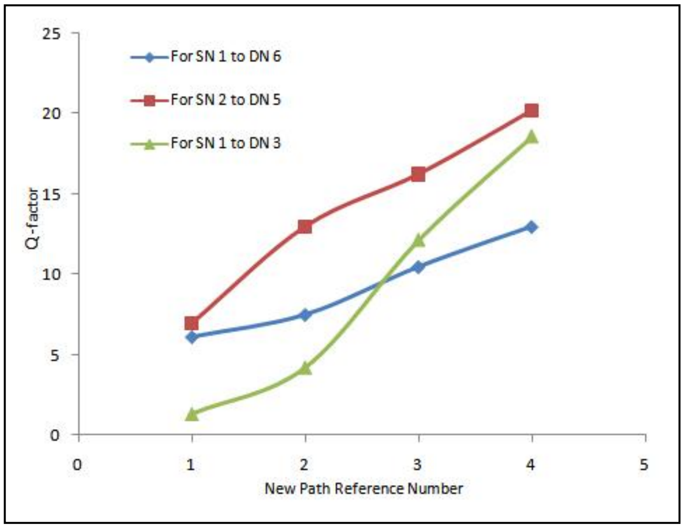

Fig. 6. Q-factor Vs New path ref. No.

V. CONCLUSION

In our simulation, we have considered power loss, path capacity and finally Q-Factor for a given source-destination pair. Our proposed algorithm helps to analyze those constraints and determines the best possible data-path in between source-destination pair. The result shows the variations of power losses, channel capacity and quality factor for all possible data-paths for the clients. Finally the best data-path has been selected based on the requirements of the client.

REFERENCES

[1] Suresh Subramaniam Chava Vijaya Saradhi, "Physical Layer Impairment Aware Routing (PLIAR) in WDM Optical Networks: Issues and Challenges," *IEEE Communications surveys & Tutorials*, vol. 11, no. 4, pp. 109-130, October 2009.

[2] Mirosław Klinkowski, Eva Marin, Davide Careglio, Josep Solé Pareta and Ioannis Tomkos Siamak Azodolmolky, "A survey on physical layer impairments aware routing and," *Computer Network*, vol. 53, pp. 926-944, May 2009.

[3] Christina (Tanya) Politib, Chris Matrakidisb, and A. Stavdasb Vasilis Anagnostopoulosa, "Physical Layer Impairment Aware Wavelength Routing Algorithms," *Optics Communications*, vol. 270, no. 2, pp. 247-254, February 2007.

[4] R. Guerin, V. Peris, and R. Rajan L. Georgiadis, "Efficient Support of Delay and Rate Guarantees in an Internet," *SIGCOMM'96*, Auguest 1996.

[5] M. Czermin, A. Riedl J. Glasmann, "Estimation of Token Bucket Parameters for Videoconferencing Systems in Corporate Networks," in *8TH International conference on computer softwar,Telecommunication and Computer Networks,SoftCOM 2000*, 2000.

[6] D. Black, M. Carlson, E. Davies, Z. Wang, W. Weiss S. Blake, "An Architecture for Differentiated Services," *RFC 2475*, 1998.

[7] Jonathan P. Heritage, and Biswanath Mukherjee Yurong (Grace) Huang, "Connection Provisioning With Transmission Impairment Consideration in Optical WDM Networks With High-Speed Channels," *Journal of Light wave technology*, vol. 23, no. 3, pp. 982-993, March 2005.

[8] A. L. Chiu, and R. Tkach J. Strand, "Issues for routing in the optical layer," *IEEE*, vol. 39, no. 2, pp. 81-87, February 2001.

[9] Stelios Sygletos, Anna Tzanakaki, and George Markidis Ioannis Tomkos, "Impairment Constraint Based Routing in Mesh Optical Networks," in *Optical Fiber Communication Conference (OFC)*, Anaheim, California, 2007.

[10] A. Tzanakaki, C. Mas Machuka, and I. Tomkos P. Kulkarni, "Benefits of Q-factor based Routing in WDM Metro Networks," in *ECOC2005*, 2005.