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Physical Layer Impairments based Data-path Routing in WDM Network

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***Abstract*— In WDM network, the quality of data flow depends not only on network layer information, but also on physical layer impairments (PLIs) constraints, which are incurred by non-ideal optical transmission media and accumulates along with the optical data-path. It is important to analysis PLIs in-order to satisfy client's necessary requirement of QoS for their data flow. In-corporate to the above point, the design methodology says how to understand the process that provide PLI information to the control plane protocols and use this information efficiently to compute feasible routes. Based on the PLI impairments, it is proposed a centralized PLI based routing algorithm for the selection of data-paths.**

Keywords- physical layer impairments; link-capacity; Q-Factor; data-path; power loss; path reference number;

I. INTRODUCTION

Day-to-day growth in telecommunication network requires functionalities like dynamic data-path (DP) routing and re-routing with guaranteed Quality of service (QoS), which are essential for any optical network. The quality of DP routing in WDM network not only depends on the network layer but also depends on the physical layer. The degradation of DP quality happens due to the affect of Physical layer impairment (PLI) constraints. PLIs are broadly classified in to two categories: linear and non-linear impairments [1]. 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 a allocated DP. Moreover, the allocation of route and wavelength for a new DP request affects the existing DP in the network. Further, a guaranteed quality of service (QoS) traffic flow requires a good traffic engineering control manager (TECM) by the service provider (SP), which can be applied at any router. This TECM can be centralized or distributed. In our design we consider a centralized base TECM, which considers network layer as well as physical layer impairment constraints [1, 2, 3] in order to obtain a guaranteed service for a client application. Such application might require a wide range of QoS guarantees from the SP.

In our work, the QoS requirements of the clients have been considered in terms of bandwidth and PLI based Q-factor. We follow [4, 5] and similarly specify our network model based on bandwidth and PLI constraints. In this paper, we focus on PLI Impairment constraints, which are defined as the parameter effect in the physical layer while establishing a source-destination connection. We have considered bandwidth and PLI model, with a simple DP selection mechanism for a set of client applications. The main objectives of this paper is to when and how to obtain a DP for the incoming traffics at the access router. We solve this problem by formulating a mathematical admission control model and a traffic aggregation model for the general purpose router (GPR) based on the idea of differentiated services [6] to maintain the quality of services for the incoming traffic.

In the next section, the network model is introduced. In section III, the problem formulation for bandwidth and PLI model are described. In section IV, the DP selection mechanism presented. In section V, we are described about the result and discussion. Finally in section VI, some conclusions are drawn.

II. NETWORK MODEL

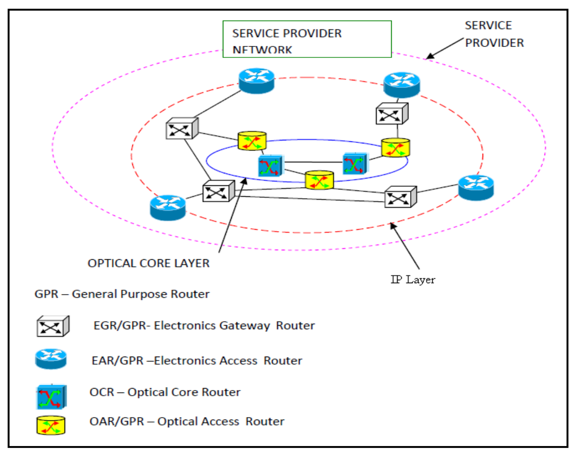

Figure 1: Network Model

The model shown in Fig. 1 tells about the network model, which is a three layer structure, the Service provider layer shown as the outermost layer, the Optical core layer which is the innermost Optical network layer and the intermediate IP layer. This is an abstraction of the combined IP-optical network which allows us to focus on that portion of the network where our innovation applies, i.e. the combination of IP and optical network. The optical layer provides point-to-point connectivity between routers in the form of fixed bandwidth circuits, which is termed as lightpaths. The collection of lightpaths therefore defines the topology of the virtual network interconnecting IP Routers. In IP layer the routers are responsible for all the non-local management functions such as management of optical resources, configuration and capacity management, addressing, routing, topology discovery, traffic engineering, and restoration etc. The IP router communicates with the TECM (Traffic Engineering Control Manager) of SP network and provides the information about the status of the optical layer.

Ideally the SP layer will include elements of the access network such as the PON (Passive Optical Network) related elements and other devices / equipment located at the premises / home. We assume that the SP has access to General Purpose Routers and also optical components in the core optical network. Such an assumption is reasonable, given the fact that the prices of optical switching equipment have fallen by orders of magnitude till the point that they are being used in the premises of large corporations in order to interconnect buildings etc. Thus it is reasonable to assume, as we have done, that the service provider has information about the GPRs and the optical equipment within its domain of control.

The SP layer controls all the traffic corresponding to both IP and optical layers. All the routers shown in the figure are controlled by the SP. The SP maintains a traffic matrix in a Traffic Engineering Control Manager (TECM) for all the connected general purpose routers, i.e. all the IP/Electronics Gateway Routers (EGR), Electronic/IP Access Routers (EAR) and Optical Access Routers (OAR) within its domain of control.

The Traffic Engineering Control Manager (TECM) maintains the network state information (Capacity and Q-Factor matrices) for all the GPRs in the network. In the following sections we outline our algorithms that carry out the computations necessary for the decisions that lead to selection of data-paths.

III. 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, $C(m,n,s,d)$ 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 $D\ (i,\ j) = L\ (i,\ j) = \infty$, 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.

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

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.

$$\delta_{eye}(i,k) = \delta_{pmd}(i,k) \times \delta_{cd}(i,k) = 10^2 \times C^2(i,k) \times D_p^2(i,k) \times L(i,k) \times \delta_{cd}(i,k) \qquad (8)$$

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

IV. Data Path Selection Mechanism

The selection of DP is based on the above equations. The edge GPR aggregates the traffic requirements of the flows as mentioned in equation 1. This aggregated traffic compares with the calculated path capacity mentioned in equation 2. The algorithm calculates the Q-Factor for the DP of *(m, n)* client for *(s, d)* pair, based on the traffic requirements. The comparison takes decision, whether to select or de-select DP for the requested services.

A. Selection of DP

We have considered two different scenarios for DP selection mechanism as follows.

Scenario 1: When average Q-Factor is less than or equals to the overall Q-factor i.e.,

$$AQF_{(m,n,s,d)} \le QF_{overall}(p(m,n,s,d)) \qquad (9)$$

If the above equation satisfy, then the corresponding best DP of $p(m,n,s,d)$ will be selected.

Scenario 2: When average Q-Factor is greater than or equals to the overall Q-Factor, i.e.,

$$AQF_{(m,n,s,d)} > QF_{overall}(p(m,n,s,d)) \qquad (10)$$

If the above equation satisfy, then the corresponding DP of $p(m,n,s,d)$ will be dropped and a new DP will be computed in-order to satisfy the requirements.

V. Simulation Results and Discussion

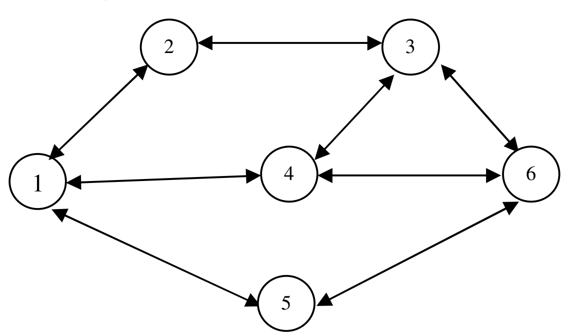

Figure 2: Network Topology for simulation

The Fig. 2 shows the basic network topology for simulation work. Here we considered three pairs of source and destination pairs ((1, 6), (2, 5), (1, 3)). The possible paths are {(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)} as path reference number 1, 2, 3, 4 respectively.

In our simulation we have taken the parameters mentioned in table1.

TABLE I
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

The table 2 shows the simulation results for computation of overall Q-Factor, best path reference number and the best path selection.

TABLE 2: Q-FACTOR CALCULATION

SN	DN	PP	Path Ref. No	$QF_{overall}$	BPP RN	AQF	BP
1	6	1-2-3-6	1	10.47	3	11	4
		1-4-3-6	2	7.88	2		
		1-4-6	3	6.09	1		
		1-5-6	4	12.98	4		
2	5	2-3-6-5	1	16.23	3	11	2
		2-1-5	2	6.99	1		
		2-1-4-6-5	3	20.18	4		
		2-3-4-6-5	4	12.98	2		
1	3	1-2-3	1	4.25	2	11	3
		1-4-3	2	1.32	1		
		1-5-6-3	3	18.61	4		
		1-4-6-3	4	12.15	3		

PP: Possible Path; BP: Best path; BPPRN: Best possible path reference number according to highest overall Q-Factor ($QF_{overall}$) ; AQF: Average Q-Factor required from Clients);

We had taken the average Q-Factor of 11 as the client requirement for all the source-destination pair and the corresponding best path (BP) is shown in the table.

Fig. 3 shows the plot of Q-Factor with respect to path reference number for all possible paths and source and destination pairs. 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.

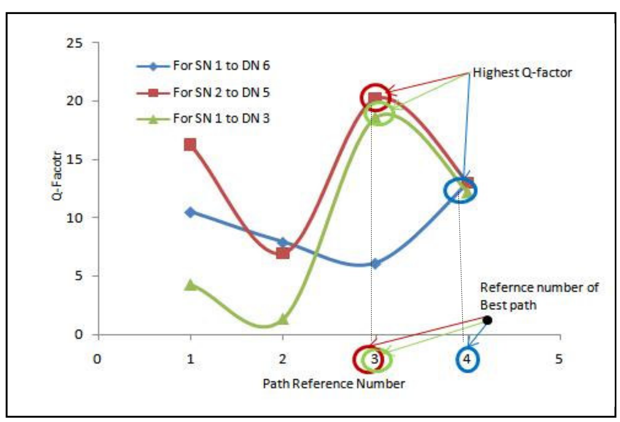

Figure 3. Quality Factor Vs. Path reference number

According to the table 2, Fig. 4 shows the plot of Q-Factor vs. the BPPRN i.e., the assigned new path reference number. From this plot, the best data-path can be selected for a source-destination pair of a client based on their required Q-Factor i.e., average Q-Factor. For example, if a client has average Q-Factor requirement (AQF) of 11 for the source destination pair (1, 6), then in accordance with the proposed algorithm, $QF_{overallL}$ >= AQF, i.e., 12.5 >= *11*, which is approaching the new path reference number 4, which will be the best path.

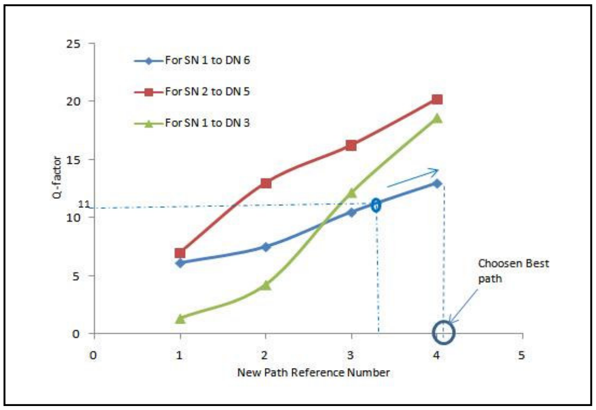

Figure 4. Q-Factor Vs New path ref. No.

VI. CONCLUSION

We have shown few of the simulations for the selection of best DP in between source and destination based on Q-Factor without client requirement and with client requirement. The above simulation has done just to say that, there are various ways of DP selections mechanisms, but one can be adopted depending on the requirements of QoS for a Client. The proposed mechanism is a centralized based algorithm, where the DP information will be analyzed by the traffic engineering control manager. That's why; the complete framework can be very useful for a service provider network.

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