Physical Layer Impairments Aware OVPN Connection Selection Mechanism

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***Abstract*—In optical virtual private network (OVPN), the quality of connection 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 connection. It is important to analysis PLIs in-order to satisfy OVPN client's necessary requirement of QoS for their connection setup. 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 connections. Based on the PLI constraints, it is proposed a centralized PLI based routing algorithm for the selection of OVPN connections.**

***Index Terms*—OVPN connection, physical layer impairments, OVPN Connection reference number, OVPN control manager, Q-factor**

I. Introduction

Day-to-day growth in telecommunication network requires functionalities like dynamic OVPN [1], [2] connection (OVPNC) routing and re-routing with guaranteed Quality of service (QoS), which are essential for any optical network. The quality of OVPNC routing in WDM network not only depends on the network layer but also depends on the physical layer. The degradation of OVPNC quality happens due to the effect of Physical layer impairment (PLI) constraints. PLIs are broadly classified in to two categories: linear and non-linear impairments [3]. 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 an allocated OVPNC. Moreover, the allocation of route and wavelength for a new OVPNC request affects the existing OVPNC in the network. Further, a guaranteed quality of service (QoS) based OVPN connection requires a good control manager by the service provider (SP), which can be applied at any router. We termed this as OVPN control manager (OVPNCM), which can be centralized or distributed. In our design we consider a centralized base OVPNCM, which considers network layer as well as physical layer impairment constraints [3] – [5] 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 computation of QoS for an OVPN client has been expressed in terms of PLI based Q-Factor. We follow [6], [7] and similarly specify our network model based on 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 a PLI model, with a simple OVPNC selection mechanism for a set of client applications. The main objective of this paper is to when and how to obtain an OVPNC for the incoming connection request at the access router. We solve this problem by formulating a centralized mathematical admission control model and an OVPN traffic aggregation model for all the optical routers (ORs) based on the idea of differentiated services [8] to maintain the quality of services for the incoming traffic.

In the next section, the OVPN system model is introduced. In section 3, the problem formulation based on PLI model is described. In section 4, the OVPNC selection mechanism is presented. In section 5, we presented the simulation result and discussion. Finally in section 6, some conclusions are drawn.

II. OVPN System Model

The OVPN layering model is shown in Fig. 1, which is consisting of two layers: the Provider layer and the Optical core layer. As shown in the model, provider edge router (PER) belongs to an OVPN client which provides OVPN service and interface between client and optical core router (OCR). An OCR is not connected to a client directly. The selection of OVPNC is the establishment of the tunnels, which may be constructed at layer 1, layer 2 and layer 3 of classical layering structure.

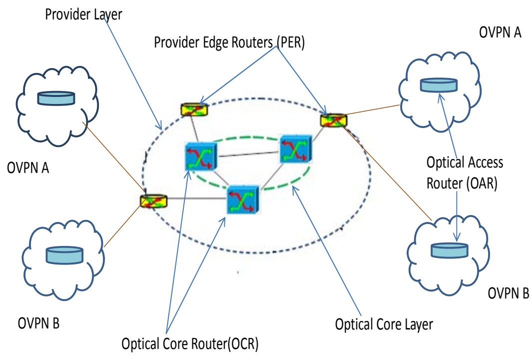

Fig. 1. OVPN layering model.

The optical layer provides point-to-point connectivity between routers in the form of fixed bandwidth circuits, which is termed as optical links. The collection of links therefore defines the topology of the virtual network

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interconnecting routers known as OVPN connection. In provider layer the PER are responsible for all the non-local management functions such as management of optical resources, configuration and wavelength management, addressing, GMPLS routing, topology discovery, traffic engineering, and restoration etc. The provider layer controls all the connection requests comes from OVPN clients. PER maintains a traffic matrix (TM) for all the connected OVPN clients within its domain of control along with a database. The TM maintains the network resources as well as physical layer impairment (PLI) constraints such as bandwidth, delay, dispersion and Q-Factor matrices for all possible OVPN connection in the network, belonging to all the layers.

In the following sections we outline our algorithms that carry out the computations necessary for the decisions that lead to provisioning/de-provisioning of OVPN connection.

In general, the model refers the combination of provider layer (electronic/IP layer) and the optical layer, which can be termed as electro-optical layer. We propose an abstraction of the combined electro-optical network which allows us to focus on that portion of the network where our innovation applies, i.e. the combined electro-optical network. OVPNCM directly communicate with optical core routers and updates its information. Ideally the provider 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. However for this invention such details are not necessary. We assume that the service provider has access to 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 optical equipment within its domain of control.

III. Problem Formulation

Network may be modeled using nodes/routers and links, which provides the layout pattern of interconnections of the various elements like links, nodes, etc. of a network system which is shown in Fig. 2. This figure says about the physical topology of the network along with the client Q-Factor requirements. The Q-Factor requirement QF_{rqd} *(m, n, s, d)* specifies for (*m*, *n*) OVPN client pair for a source (*s*) and destination (*d*) PER pair. In a network, a node is a connection point, either a redistribution point or an end point for data transmissions. Nodes are represented by the coordinate system where the location of a node is given by point in a coordinate system. Link in a network is a connection through optical fiber link between two nodes.

Connectivity in a system: Connectivity is determined by the connection between two nodes. If there is a link present between two nodes connectivity is taken as '1' otherwise it is taken as '0'. Using this connectivity matrix, OVPN Connection can be determined.

Let's consider this network topology is having *n* number of nodes as shown in Fig. 2.

If *i* and *j* are the node/router pairs, then the connection metrics *T (i, j)* can be as follows:

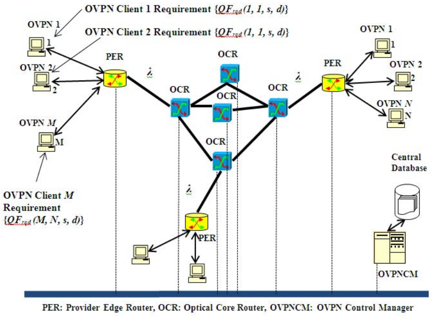

Fig. 2. Physical topology

$$T(i,j)=\begin{cases}1 & \text{If link between } i \text{ and } j \text{ is exist}\\ 0 & \text{otherwise}\end{cases} \tag{1}$$

All the routers shown in the Fig. 2 are controlled by the provider network, which is called as the control plane.

We consider a topology with a number of OVPN connection requests from the client source to client destination. These connection requests can be aggregated at the source node. We formulated a PLI based model depending on OVPN clients Q-Factor requirement and available/computed resources in the following section.

Suppose an OVPN connection request from client *m* to client *n* with source *s* to destination *d* has Q-Factor requirement QF_{rqd} (*m, n, s, d*). For every edge router, a free available connection bandwidth metrics (CBM) $B(m,n,s,d)$ has been considered.

If *D (i, j)* is the dispersion of the fiber and *L (i, j)* is the length of fiber link pair *(i, j)*, then the link bandwidth metrics $B(i,j)$ can be explained [9] as follows:

$$B(i,j)=\frac{\delta}{DS(i,j)\times\sqrt{L(i,j)}} \tag{2}$$

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 [10] and *D (i, j) = L (i, j) = ∞*, when there is no link between i^{th} *and* j^{th} node.

The CBM $B(m,n,s,d)$ calculation is derived from a single link to a group of links in an OVPNC (represented as *p*) as follows:

$$B(m,n,s,d)=Min\ \{B(i,j)\},\forall(i,j)\in p \tag{3}$$

The optical domain involves with variety of PLIs and their impact on the overall network performance. In order to get a suitable OVPNC based on the link cost, we need to consider PLI constraints in terms of Q-Factors. We define the Q-Factor as the link cost corresponding to a connection as mentioned in [11]. The Q-Factor (QF_i) for i^{th} node for a *(s, d)* pair can be expressed n mathematically,

$$QF_i=\frac{\sum_{k=1}^{N_i}10\log\left[Q_{i,k}^{s}/Q_{i,k}^{d}\right]}{N_i} \tag{4}$$

where, N_i is the number of wavelengths at the i^{th} node, $Q_{i,k}^{s}$ and $Q_{i,k}^{d}$ are the quality factor measurements of the k^{th}

connection for the source (s) and destination (d) node of the i^{th} node respectively.

If $p(m,n,s,d)$ is the OVPNC containing l number of links, the computed Q-Factor $QF_c(p(m,n,s,d))$ will be:

$$QF_c(p(m,n,s,d)) = \sum_i^l QF_i \tag{5}$$

Further according to [12],

$$\frac{Q_{i,k}^s}{Q_{i,k}^d} = \frac{1}{(\delta_{eye}(i,k)) \times (\delta_{noise}(i,k))} \tag{6}$$

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

Then equation 4 becomes,

$$QF_i = \frac{\sum_{k=1}^{N_i} 10 \log\left[1/(\delta_{eye}(i,k)) \times (\delta_{noise}(i,k))\right]}{N_i} \tag{7}$$

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.

where,

$$\delta_{noise}(i,k) = \frac{P^d}{p^s} \times \frac{1}{\sqrt{F}} \tag{8}$$

$$\delta_{eye}(i,k) = \delta_{pmd}(i,k) \times \delta_{cd}(i,k)$$

This can be written as,

$$\delta_{eye}(i,k) = 10.2 \times B^2(i,k) \times D_p^2(i,k) \times L(i,k) \times \delta_{cd}(i,k) \tag{9}$$

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 OVPNC.
where, $B(i,k)$ is the bandwidth, $D_p(i,k)$ is the PMD parameter and $L(i,k)$ is the connection length.

IV. OVPN Connection Selection Mechanism

The algorithm computes the Q-Factor for the OVPNC of *(m, n)* client for *(s, d)* pair, based on with or without Q-Factor requirements. The comparison takes decision, whether to select or de-select OVPNC for the requested services.

We proposed two cases of OVPNC selection mechanism as follows:

A. Case 1: Optimal OVPN Selection, When there is no Q-Factor Requirement.

Assuming for a given source-destination pair (s, d), there are K possible OVPN connections are available with different Q-Factor values. Out of them the connection, which will have highest Q-Factor value that will be selected as an optimal OVPN connection.

Let the Q-Factor of k^{th} OVPN connection can be represented as $QF(OVPN_{(s,d)}^k)$, where k is the OVPN connection reference numbers i.e., *k Є {1, 2, 3. . . K}*.

The main objective function, of our work is to find an optimal OVPN connection, which can be expressed as follows.

$$QF_o(s,d) = Max\{QF(OVPN_{(s,d)}^k)\} \tag{10}$$

B. Case II: OVPNC Selection, When there is Q-Factor Requirement.

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

Scenario 1: When the required Q-Factor is less than or equals to the computed Q-Factor i.e.,

$$QF_{rqd}(m,n,s,d) \le QF_c(p(m,n,s,d)), \forall p \in P \tag{11}$$

P is a set of connections for a (s, d) pair, which can be computed by using generic path finding algorithm. The connection, which satisfies the above condition, will be the selected OVPNC.

Scenario 2: When required Q-Factor is greater than to the computed Q-Factor, i.e.,

$$QF_{rqd}(m,n,s,d) > QF_c(p(m,n,s,d)) \tag{12}$$

If the above equation satisfies, then the corresponding OVPNC from the set P will be dropped and a new OVPNC will be computed in-order to satisfy the requirement.

V. Results And Discussions

We assume the 6 node topology for simulation using MATLAB. The Fig. 3 shows the basic network topology for simulation work.

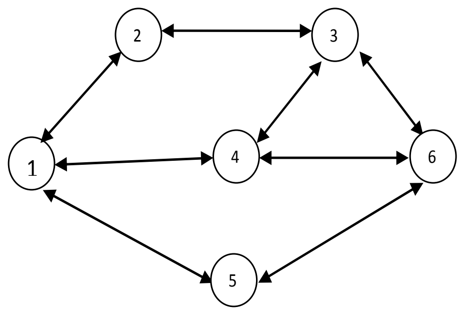

Fig. 3. Network topology for simulation

Here we considered three source and destination pairs (1, 6), (2, 5) and (1, 3)), whose possible connections 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)} and {(1-2-3), (1-4-3), (1-5-6-3), (1-4-6-3)} respectively. All the source-destination pairs have same number of connections with OVPNC reference numbers 1, 2, 3, 4 respectively.

In our simulation we have assumed the parameters mentioned in TABLE I.

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

We also assumed two cases for the selection of OVPNC as follows:

A. Case 1: Optimal OVPN Selection, When there is no Q-Factor Requirement.

In this case an optimal OVPNC with highest Q-Factor will be selected.

Fig. 4 shows the plot of Q-Factor with OVPNC reference numbers for a given source and destination pairs. Corresponding to the highest Q-Factor values, the selected OVPNC for (1, 6), (2, 5), and (1, 3) are (1-5-6), (2-1-4-6-5), and (1-5-6-3) respectively.

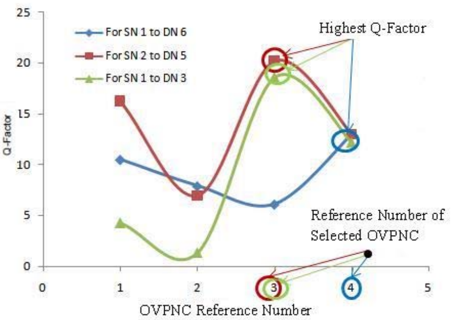

Fig. 4. Graphical representation of Optimal OVPNC selection

B. OVPNC selection, When there is Q-Factor Requirement.

The TABLE II shows the simulation results for computation of Q-Factor with the selection of OVPNC.

TABLE II: Q-FACTOR COMPUTATION WITH OVPNC SELECTION

SN	DN	PO	PRN	QF	NO RN	RQF	SO
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		

(Note = SN: Source Node, DN: Destination Node, PO: Possible OVPNC, SO: Selected OVPNC, NORN: New OVPNC reference number newly assigned according to Q-Factor in incremental order, RQF: Required Q-Factor from Clients)

We assumed the required Q-Factor of 11 from all the OVPN clients and accordingly the corresponding suitable OVPNC are shown in TABLE II for all the source-destination pair.

According to the TABLE II, Fig. 5 shows the plot of Q-Factor with respect to new OVPNC reference number, which are newly assigned according to Q-Factor in incremental order. From this plot, the suitable OVPNC can be selected for a source-destination pair of a client based on their required Q-Factor.

For example, if a client has required Q-Factor (QF_{rqd}) of 11 for a source destination pair (1, 6), then in accordance with our proposed mechanism, $QF_{rqd} <= QF_{c}$, i.e., 11 < = 12.98, which is approaching the new OVPNC reference number 4 and will be the selected OVPNC.

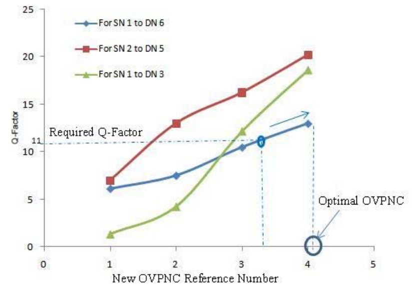

Fig. 5. Graphical representation of OVPNC selection with clients Q-Factor requirements)

VI. CONCLUSION

We have shown few of the simulations for the selection of OVPNC for a source and destination pair based on Q-Factor with and without OVPN client requirement. In both the above cases, the analysis of OVPNC selection mechanism has different advantages. In case I, an optimal OVPNC will be assigned to the client, which can provide maximal QoS. In case II, an OVPNC will be assigned as per the required Q-Factor, which might reduce the complexity of the selection mechanism and will be faster than case I. The above simulation has done just to say that, there are various ways of OVPNC 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 OVPNC information will be analyzed by the OVPNCM. That's why; the complete framework can be very useful for a service provider network.

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