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Selection of Lightpath for BER and PMD Constraints

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Abstract- *In this paper a novel technique is given to detect the impairments occurring during 10Gb/s and 40Gb/s transmission and prepare RWA algorithm in which the occurred impairments are taken into considerations. Since there are several impairments occurring the paper deals with Polarization mode dispersion and BER. An algorithm is prepared for selecting the suitable lightpath at which BER is less than the threshold value and PMD is removed by mathematical implementation. Reduction in the impairment reduces the call blocking probability and the computation cost for transmission. Designing of algorithm for suitable lightpath selection is helpful in data transmission at the rate of 10 Gb/s and 40 Gb/s.*

Keywords: *Linear impairments, PMD, Bit Error Rate (BER), Dispersion Slope, RWA.*

I. Introduction

In addition to providing enormous capacities in the network, an optical network provides a common infrastructure over which a variety of services can be delivered.WDM network offers much higher bandwidth than copper cable and is less susceptible to various kinds of electromagnetic interferences and other undesirable effects.WDM history started with opaque network, in which there was O-E-O conversion at each node that means that the optical signal carrying traffic terminates at each node to undergo O-E-O conversion. This approach had full independence between the network and physical layer but it also required a large amount of O-E-O conversion devices that increased the network cost and energy consumption. In transparent optical networks, no O-E-O conversion is involved and the optical signal at the source node reaches the destination through intermediate nodes. This approach reduced the cost, but also implied that physical layer must support end-to-end communication. The transmission is although affected due to impairments that occurs in the physical layer. These impairments cause the transmitted data not to be received correctly at the destination. Since the data that has been transmitted for the entire lightpath, remains in optical domain, the signal is degraded due to the accumulation of noise and signal distortions. Thus due to the accumulation of these impairments at the destination the received signal quality may be so poor that BER can reach an unacceptably high value and thus the lightpath is not usable. Thus, a QoT estimator is needed that accounts for the physical layer impairments occurring in the path and is able to determine the signal quality needed. The physical layer impairments that occur during the transmission are of two types: linear and non-linear impairments. Linear impairments are static in nature, independent of signal power and affect each wavelength individually whereas non-linear impairments are dynamic in nature, depends on signal power and it not only affects the individual channel but also causes disturbances in between the channel.

The paper here deals with new connection provisioning algorithms that provide guaranteed signal quality connection in WDM mesh network. In literature there are various QoT estimators based on the numerical calculations of the Bit Error Rate (BER) applying analytical formulas, or interpolating numerical and laboratory measurements, to compute the Q factor values. The Q factor of a lightpath is in direct relation to its signal BER performance. For example, to evaluate a feasibility of a lightpath in QoT in terms of OSNR must be higher than 19 dB for a 10 G system, it must be lower than 10^{-9} in the case of BER, or it must be higher than 15.5 dB in case of Q-factor[6].Our goal in this paper is to design intelligent algorithms which can improve the network performance by choosing the best suited path for the signal to be transmitted at the rate of 10 Gb/s by considering the impact of network impairments and to access the network performance.

II. Challenges Of Lightpath Selection

Here we focus on a number of challenges that occur during the selection of lightpath for transmission now-a-days which includes OSNR, dispersion and dispersion slope and PMD. Today most of the work is being done on transmission at the rate of 40Gb/s so meeting these challenges is an important measure. It has been difficult but 40Gb/s electronics have shown good progress indicating that performance to the same standard as 10Gb/s electronics will be possible. Given below are the brief discussions about the challenges in WDM transmission.

2.1 Optical Signal To Noise Ratio

Increasing the line rate from 10Gb/s to 40Gb/s requires a 6dB increase in the received OSNR[2]. The best suited method for receiving the OSNR in 40Gb/s is the distributed Raman amplification used in conjunction with discrete Erbium Doped Amplifier [EDFA]. This method involves terrestrial span losses of 23 to 25 dB (i.e. 100 km).There are various advantages in the Raman amplification like it provides gain at any wavelength and low noise figure from signal spontaneous beating. But it also has some drawbacks like requirement of relatively high pump power and the need for amplifier designs to minimize the impact of double Rayleigh scattering and fast response time of the gain.

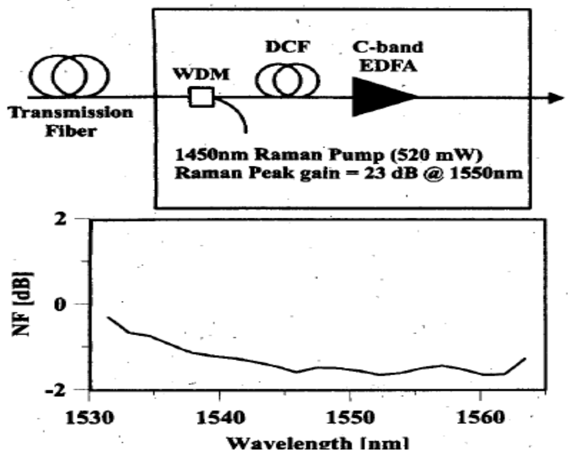

Figure1. Schematic diagram and effective noise figure of hybrid Raman/Erbium C-band amplifier [2]

2.2 Dispersion and Dispersion Slope

For a 40Gb/s non return to zero (NRZ) signal, the theoretical dispersion tolerance is approx 60ps/nm, which implies that precise dispersion management is required. When the dispersion slope of the dispersion compensating modules (DCM) matches that of the transmission fiber, all WDM channel experiences the same optimum dispersion map [2,5]. The loss of the high order module (HOM) compensator, combined with the tolerance to higher launched power, improves the overall power budget in a transmission link.

2.3 Polarization Mode Dispersion

When a signal propogates through a fiber with PMD, it experiences various factors like group delay due to polarization dependency and pulse distortion which results in system penalties. Also, PMD becomes difficult to be managed due to environmental changes and stress that causes fiber PMD to vary with time and wavelength. A number of optical PMD compensators have been proposed and demonstrated at 40G/s, but electronic PMD compensation at 40Gb/s has yet not been achieved [7,9].

2.4 Polarization Multiplexing

If the WDM channels are polarization multiplexed then spectral efficiency of .8 bit/s/Hz can be achieved. There were recently held WDM experiments with polarization multiplexing at 40Gb/s per channel and .8 bit/s/Hz spectral efficiency in order to remove worst case impairments caused by PMD in the fiber. In these experiments it was found that the impairments are caused by the crosstalk that are induced in the PMD between the channels[2].The analysis showed that crosstalk occurs because for a fixed input polarization, PMD causes the output polarization to vary with frequency. Polarization multiplexing is being employed for further enhancement in spectral efficiency.

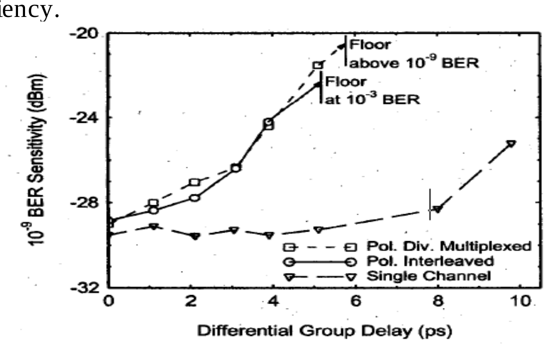

Figure 2. Comparison of the PMD tolerance of polarization division multiplexing and polarization interleaving for NRZ[2,7]

Thus, these are the key challenges for WDM transmission. The challenges can be met by integrated circuits which are Si-Ge and/or InP based. Design of Raman amplifier is improved by new low PMD fibers. .

III. Selection For Intelligent Lightpath And RWA

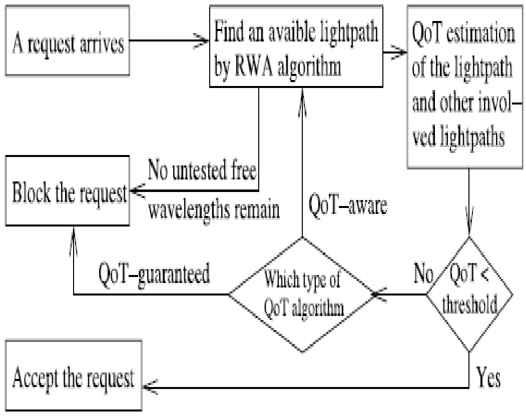

Figure 3. Flowchart of QoT algorithm incorporating both wavelength blocking and QoT blocking [2]

Demands for all optical lightpaths can be static or dynamic. In the static mode, a traffic matrix represents lightpaths required for every node pair [4]. In the dynamic mode, connections are established over time and are not known beforehand. In this paper dynamic provisioning of lightpaths in optical networks is addressed. If a request is to be send from ingress node s to egress node d then first a suitable lightpath and a wavelength is to be chosen. There are mostly three methods mentioned in various papers to select the lightpath. These are Best Fit (BF). First Fit(FF) and RAND. In Best Fit all the wavelengths used for transmission are investigated and that wavelength which provides lowest BER is selected. In First Fit the first wavelength with lowest BER is selected for transmission. In RAND a wavelength is chosen randomly and is checked for its BER. Among the randomly chosen wavelengths the one with the lowest BER is chosen and the lightpath with that wavelength is used for data transmission for all the above mentioned methods algorithm has to be designed following which the required wavelength is chosen. Out of the three methods best is the BF i.e. impairment aware best path algorithm(IABP) because it along with giving the wavelength with lowest BER also chooses the shortest lightpath among all the available lightpaths. Thus, IABP has a nature of allocating wavelengths without order, but under a certain control that chooses the lightpath with minimum distance from all available shortest paths.

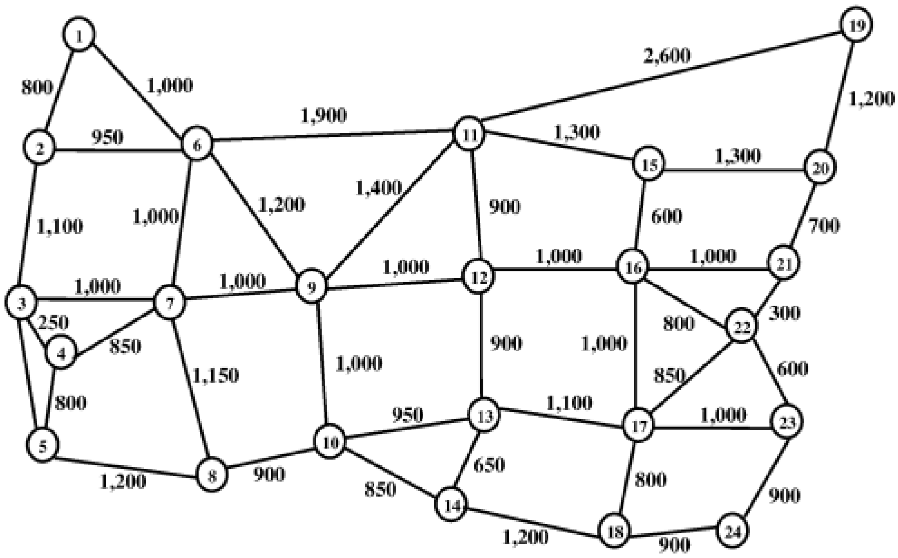

Figure 4. A sample mesh network with fiber length(in km) marked on each link [1]

- The optical transparent WDM network consists of multiple nodes connected by optical fiber in an arbitrary topology is shown in above figure [1].

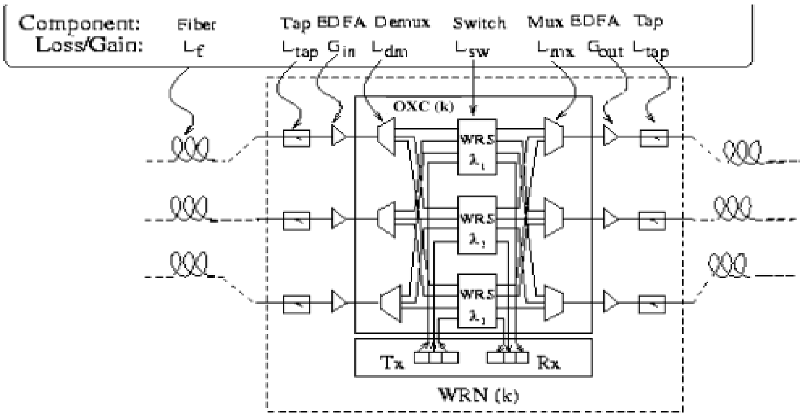

Figure 5. Architecture of Wavelength Routing Node[1]

- Figure consists of an OXC and transmitter/receiver array .The wavelength-routing switches (WRS) in OXC are considered to employ a non-blocking active splitter /combiner. The EDFA in node compensate both the internal losses of OXC and loss of fiber segment.

3.1 Impairment Aware Best-Path Algorithm

Step1- In the first step, by the use of shortest path algorithm, find the path Pw in WS_w for w=1,2,………,W. A vector of path distances is defined as $d=\{d_w(w=1,2,\ldots\ldots,W)\}$. Then d_w is set to ∞, If no lightpath is available in wavelength-layered topology WG_w. Otherwise, d_w is defined as the total distance of path P_w.

Step2- If in d, all the elements are not ∞, then find the minimum distance $d_m \in d$ and mark the candidate $\lambda = m$. If all the elements in d have the value ∞, the call is blocked and the procedure is stopped.

Step3- Send the lightpath P_λ for the estimation of lightpath quality to find whether the lightpath quality is good or not and waiting for feedback.

Step4- If the estimation of lightpath quality is "acceptable", firstly, the call is being setup by using P_λ ,then update WS_λ by specifying the links which have been used by P_λ . Atlast, the physical layer information is updated by recording the signal powers as well as noise powers on each link along the lightpath P_λ.Otherwise, update d_m to ∞ and again repeat the step (2).

Step5- Stop the procedure.

3.2 Impairment Aware First-Fit Algorithm

Step1- In this type of algorithm, first consider the wavelength w=1 i,e, first wavelength.

Step2- In the next step, to find the path Pw in WS_w by applying the shortest path algorithm. If there is no available path in WS_w , let w= w+1. Repeat this step until we will find the desired path in one of wavelength-layered topology graphs and mark the candidate wavelength λ=w.

Step3- If there is no path is available in all wavelength layered topology graphs WS_m ,the call is blocked and the procedure is stopped.

Step4- The lightpath P_λ is given for the estimation of lightpath quality and wait for the feedback whether the quality of lightpath is good for admitting the call for setup. If the quality of lightpath is not good, Then the current lightpath is marked as unavailable and compute a next lightpath from available resources.

Step5- If the estimation of lightpath quality is "acceptable", firstly, the call is being setup by using P_λ ,then update WS_λ by specifying the links which have been used by P_λ . Atlast, the physical layer information is updated by recording the signal powers as well as noise powers on each link along the lightpath P_λ. Otherwise, w=w+1 and go to step (2).

Step6- Stop the procedure

IV. BER Limit

BER is a comprehensive criterion for evaluating signal quality. Expression for BER at the WDM receiver is

$$Pe = \frac{1}{2} * erfc\left(\frac{d}{\sqrt{2\sigma th^2}}\right) + \frac{1}{8} * erfc\left\{\frac{Is-1}{\sqrt{2\sigma th^2}}\right\} + 1/2^{\wedge}(N+3)\{\pi f(Is-d)\}\sum erfc\{\frac{Is-Ak}{\sqrt{2\sigma^2}})\}$$

The above equation has been taken from [10].From the above equation power penalty is found by comparing the photocurrent at the receiver that produces the same BER with and without dispersion.

Below is given an algorithm which considers the BER constraint while selecting the lightpath. Our motive while designing this algorithm is to keep BER below the threshold value that is taken as 10^{-9}.

Step1-The ingress node makes a connection request with desired QoT.
Step2-For the request, a shortest lightpath is chosen using BF or FF method.
Step3-In case the connection is found the wavelength is assigned at which the request has to be sent.
Step4-If the connection is not found, the call is blocked.
Step5-BER is selected on the selected lightpath connection.
Step6-This estimated BER is compared with the threshold BER(10^{-9}). If BER<10^{-9}, request is accepted else the procedure is repeated by choosing another lightpath.

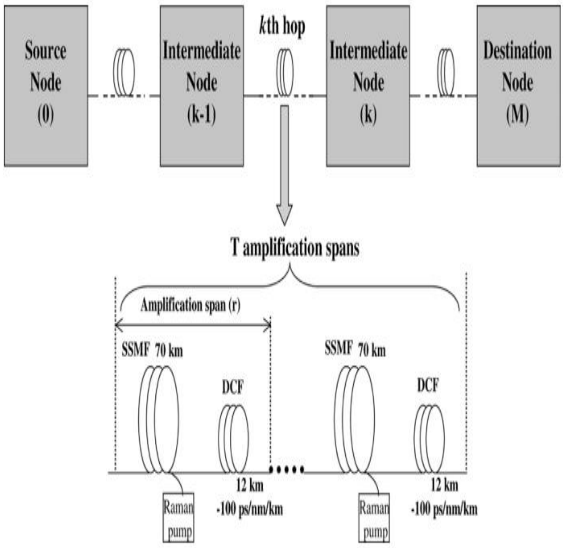

Figure 6. Simulated Lightpath Architecture [1]

V. PMD Limit

PMD becomes one of the limitation if the data is to be transmitted at a bit rate 10Gb/s and higher. The PMD limit beyond which a call cannot be routed is given by [1]

$$B \times \sqrt{\sum_{k=1}^{M} D^2_{\text{PMD}}(k) \times L(k)} \leq \delta$$

In the above equation B is the data rate, $D_{PMD}(k)$ is the fiber PMD parameter in the kth hop of the transparent lightpath consisting of M hops, L(k) is the fiber length of the k^{th} hop. Parameter delta represents the fractional pulse broadening which should be less than 10% of a bit's time slot so that PMD can be tolerated. Although different fibers have different values of D_{PMD}, in the paper all fibers have been assumed to have same D_{PMD}.

VI. Conclusion

This paper investigates impairments that occur during high data rate transmission in an all optical WDM mesh network operating with high speed wavelength channels. In the presence of impairments the quality of signal is affected resulting in high computation cost and call blocking.So various techniques are required to mitigate the impairments effects on network performance. The literature here developed a RWA model where the PMD and BER effects were estimated. The RWA algorithm designed considers the impairment affects and choses the lightpath which has minimum effect of PMD and BER. The impairment aware algorithm designed here provides better signal quality, reduction in call blocking probability and utilizes network resources in a better way.

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