CONSIDERATION OF PHYSICAL IMPAIRMENTS IN ALL OPTICAL WDM NETWORKS

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Abstract— This paper investigate the impact of different physical impairments in the performance of all-optical networks to efficiently provide signal-quality-guaranteed connections in an optical wavelength-division-multiplexing (WDM) mesh network operating with high-speed wavelength channels. In an optical network, a connection is set up to carry a data signal via an all-optical channel (lightpath (LP)) from its source to destination node. The optical signal transmitted along the LP may need to travel through a number of crossconnect switches (OXCs), optical amplifiers, and fiber segments. While the signal propagates toward its destination, the optical components would continuously degrade the signal quality by inducing impairments. When the signal degradation is so severe that the received bit-error rate (BER) becomes unacceptably high, the LP would not be able to provide good service quality to a connection request. Such a LP, which has poor signal quality due to transmission impairments in the physical layer, should not be used in the network layer. With increasing channel bit rate to 10Gb/s or higher, fiber linear and nonlinear impairments become prominent factors, which affect the signal quality. Thus, a new technique in physical layer is necessary for mitigating impairments to accommodate high-speed traffic. Physical impairments originating from optical fiber components and intermediate switching nodes can be the dominant reason calls are blocked in all-optical wavelength division multiplexing (WDM) networks. Estimating the impact of the physical impairments on the quality of a LP before provisioning it can cause a significant delay. The main contribution of our paper is that the optical signal-to-noise ratio (OSNR), loss and delay effect are estimated in the physical layer and regarded as metrics for LP computation in the network layer.

***Keywords*— optical signal-to-noise ratio (OSNR), optical WDM network, Loss, delay, signal quality, transmission impairment, Bit error rate(BER).**

I. INTRODUCTION

A transparent optical WDM network is a promising candidate for the next-generation backbone network. In this network, the signal remains in the optical domain between the edge nodes, i.e., the signal propagates along the optical network without suffering any optical-electrical-optical conversion. The eventual goal of reduction of OEO conversion and electronic switches leads to the concept of the all-optical transparent network [1][3]. It has been shown that the economy and scalability of the network are greatly enhanced through the use of a transparent networking layer [1]. Hence, we focus our attention on such a transparent network wherein a connection is set up to carry data traffic via an all-optical WDM channel, called a *lightpath*. Because of transparency of an all-optical network, the elimination of OEO conversion leads to the loss of a potential benefit that signal degradations will be cleaned up when the signal is regenerated at intermediate nodes. Since a transmitted data signal remains in the optical domain for the entire LP, noise and signal distortions due to impairment effects accumulate while the signal travels through the LP, and they may cause significant signal degradation. At the destination node, the received signal quality may be so poor that the bit-error rate (BER) can reach an unacceptably high value, and thus the LP is not usable [5][7]. In an optical network, since LPs are setup through a variable number of independent fiber links, which may have different physical characteristics, the end-to-end transmission impairments will vary with each LP. Setting up a new LP may slightly increase the received BER of existing LPs, while tearing down an existing LP may slightly decrease the received BER of remaining LP. The control plane of an optical transparent network should incorporate the characteristics of the physical layer in setting up a LP for a new connection. To greatly simplify the network management, some margin in BER requirement could be considered to mitigate the effects of traffic distribution on a LP's quality due to the BER fluctuation.

The transmission impairments induced by non-ideal physical layer components can be classified into two categories: linear and nonlinear. Some important linear impairments are amplifier noise, polarization mode dispersion (PMD), group velocity dispersion (GVD), component crosstalk, etc.; and some important nonlinear impairments are four-wave mixing (FWM), self-phase modulation (SPM), cross-phase modulation (XPM), scattering, etc. The linear impairments are independent of signal power. Their effects on end-to-end LP might be estimated from link parameters, and hence could be handled as a constraint on routing [8]. The nonlinear effects are significantly more complex.

Our goal in this paper is to assess how network performance could be affected by transmission impairments. Instead of considering all impairments in a transmission system, our study is based on the assumption that the dominant impairments of a transmission system is noise of Erbium Doped Fiber amplifier, which is significant linear impairments in high-speed (10 Gb/s) networks .

In the physical-layer module, we model the impairment effects and keep track of them as the signal travels through a LP. The signal quality is analytically estimated at the LP's destination, and provided as feedback to the network-layer. A blocking event, called wavelength blocking, occurs when a LP cannot be set up due to shortage of a free route or a jointly free wavelength along the route. A call/request can also be blocked if the chosen LP has unsatisfactory BER, called BER blocking, or if the latency incurred in processing the call exceeds a given constraint, called latency blocking.

II. PHYSICAL IMPAIRMENTS MODELING

Our formulation quantifies the OSNR degradation along the optical signal propagation in the all-optical network. The impact of physical layer impairments is taken into account by considering the signal power and the noise power at the destination node, both affected by gains and losses along the lightpath. Moreover, network elements add noise components. Fig. 1 shows the network devices considered in our model in each link. The links has the following elements: transmitter, optical switch, multiplexer, booster amplifier, optical fiber, pre-amplifier, demultiplexer, optical switch and receiver. The points a until h are measurement points where the signal and noise can be determined in the optical domain. In point a, we have the input optical signal power (P_{in}) and the input optical noise power (N_{in}). The ratio between Pin and Nin defines the OSNR of the transmitter ($OSNR_{in}$). For the LP with k links, the elements between b and h are repeated k times before the signal reaches the receiver in the destination node.

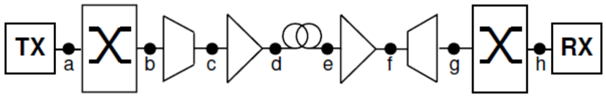

Fig. 1 The link configuration with optical devices considered in our model.

At points b and h in Fig. 1, we consider the noise induced by homodyne crosstalk in the optical switch. This occurs basically because the energy of one optical signal can leak to other co-propagating signals due to non-ideal optical switches. This occurs basically because the energy of one optical signal can leak to other co-propagating signals due to non-ideal optical switches.

A. Physical-Layer Module

BER, which considers the effects of all the impairments, is a comprehensive criterion for evaluating signal quality. The impact of impairments taken into consideration in a high speed network, we consider noises (i.e., node noise including OXC crosstalk and EDFA ASE noise, and including ASE noise and multipath interference) as dominant factors that affect signal quality. Constraints imposed by optical signal-to-noise ratio (OSNR) are used in our physical- layer module to evaluate the signal quality of a connection. The LP computed by taking only the OSNR into consideration might not guarantee that the BER requirement would be satisfied because of other types of physical impairments. However, a LP not satisfying OSNR will not be able to satisfy the BER requirement and should be blocked. Hence, at a minimum, OSNR must be taken into account, and we consider this here because it is the dominant impairments in a high-speed (10 Gb/s) transmission system.

OSNR Constraint Model: A Q factor [10] can be used as a good intermediate parameter for BER and OSNR. As an example, a BER of 10^{-9} corresponds to a Q factor equal to six with the Gaussian noise approximation while Q factor can be approximated as [20]:

$$Q=\sqrt{(Bo/Be)}*(2*OSNR)/(\sqrt{((4*OSNR)+1)}+1) \quad (1)$$

Where B_0 is optical bandwidth and B_e is electrical bandwidth. The OSNR of a single amplifier stage is determined by the following equation:

$$OSNR=(P_{IN})/(NF_{STAGE}hvf) \quad (2)$$

P_{in} = Amplifier input power (dB)

NF_{STAGE} = NF for the amplifier stage (dB)

$$NF=SNR_{INPUT}/SNR_{OUTPUT} \quad (3)$$

h = Planck's constant (6.6260×10^{-34})

v = Optical frequency constant (193 THz)

f = Bandwidth constant that measures the NF (0.1nm)

The fiber attenuation of SSMF 0.2 dB/km. In a multispan system, it is good to consider the highest span loss (worst case) and use its value in OSNR calculations. The final OSNR for an N-stage amplification system is determined by the following equation:

$$OSNR_{FINAL}=P_{in}-P_S-NF-10Log_{10}(N)-10Log_{10}(hvf) \quad (4)$$

P_{in} = Amplifier input power (dB)

P_S = Total span loss (dB)

NF = NF of the amplifier (dB)

N = Number of spans

h = Planck's constant ($6.6260 * 10^{-34}$)

□ = Optical frequency constant (193 THz)

f = Bandwidth constant that measures the NF (0.1 nm or 12.5 GHz)

III. SETUP LATENCY

The LPs are reserved in a circuit setup phase and released in a circuit tear-down phase. In networks the controller allocates the resources through the entire LP for each request during the connection admission control (CAC) procedure. In delay-sensitive networks, the delay incurred during the CAC procedure, labeled D_a, can be unacceptably long. We assume a *timeout* mechanism with a user-adjustable delay bound T_{max} ,which depends on the application. The controller takes the call at the head of the queue and iterates through candidate LP until it has found one satisfying the BER constraint (if one exists), for as long as this latency constraint is not violated. The total call admission time for call request can be written as the sum of two delays, a queuing delay and a processing delay,

$$D_a(k) = D_q(k) + D_p(k) \quad (5)$$

The queuing delay $D_q(k)$, which is the time request k must wait in the queue, depends on the sum of the processing delay of previous requests in the queue. The processing delay $D_p(k)$ includes the time required to check the routing table and the time to find a viable wavelength. The time required for calculating the set of free wavelengths is denoted τ_{LP}, and the time needed for checking if the BER of a candidate or interacting LP is higher than the BER threshold is denoted τ_c. When using the fixed alternate routing algorithm, the time to find all free wavelengths in primary and alternate routes is 2 τ_{LP}. The time to estimate the BER of a call depends directly on the network traffic and the instantaneous network state, and also indirectly on the number of hops in the LP and the severity of the physical impairments. The delay in processing k request is calculated as

$$D_p(k) = a\,\tau_{LP} + \sum_{(i=1 \text{ to } m)} Yi\,\tau_c \quad (6)$$

as long as the delay constraint is not exceeded, where is equal to 1 the path with the shortest fiber length. m denotes the number of trials before the processor finds a viable (BER less than threshold) LP or finishes checking all candidate LPs. Assuming there are E_i existing LPs that interact (share a link or node) with LP i, Yi is equal to 1+ E_i if every interacting LP is tested for BER compliance. If one interacting LP fails the compliance test, the process is terminated for the th candidate LP, and Yi is then the number of interacting LPs tested before the failure occurs. The moment the delay exceeds T_{max} , the call is instantly dropped. Networks that ignore physical impairments suffer primarily from transmission delay and propagation delay in their CAC process [12];the queueing and processing delays are small if no complex computation is performed. The analyses considered here impose a significant processing delay because of the time needed to estimate the BER. Since the transmission and propagation delays are expected to be small in comparison to $D_p(k)$, they are ignored in this paper so as to simplify the derivation. Thus, the total setup latency for call k, $D_a(k)$, is estimated as just the sum of the processing delay and queuing delay if within the *timeout* threshold.

IV.CONCLUSION

In this paper, we study the impact of guaranteeing signal-quality in an all-optical WDM mesh network operating with high-speed wavelength channels, incorporating both BER and latency constraints. Under high-speed data rate, the impact of transmission impairments on a LP's quality can become very prominent, requiring appropriate techniques in both the physical layer and the network layer to mitigate the impairment effects on network performance. Therefore, focusing on physical layer, OSNR and Latency effect were estimated in the physical layer, and regarded as metrics for high-speed connection provisioning in the network layer. The major network performance of connection-blocking probability was measured under different in-line amplification scenarios including all-EDFA amplifications. The effects of channel bit rate were studied. With signal-quality consideration, as compared to analyses that are not impairment aware in a realistic optical network, our proposed impairment-aware analyses efficiently provide signal-quality-guaranteed connections while significantly reducing connection-blocking probability , better utilizing network resources, and having a reasonable computational requirement. This study can be extended for non linear impairments.

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