Route Selection Based on Impairments Computation in All-Optical CDMA-WDM Networks

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Abstract

Link and switch impairments such as attenuation, dispersion, four-wave mixing, nonlinearities, etc. affect the optical signal quality (Q) or the optical signal to noise ratio (OSNR) in all-optical networks. The impairments not only degrade the performance of the individual links within the network, but also produce challenges for the routing procedure. It is not practical to fully integrate all photonic-specific attributes in the route selection process. In turn, new routing parameters and constraints must be defined that reflect the distinct characteristics of photonic networking. These constraints are applied to the design phase of all optical networks. Thus, these constraints are expressed as a cost (or metric form) that will be used in the network routing algorithm.

Keywords: Routing in all-optical switching, OCDMA-WDM, fiber metrics, switch metrics

1. Introduction

To date, no practical and efficient routing algorithm has been defined to find the best lightpath between ingress and egress nodes in all-optical networks. It is worth mentioning that all-optical networks can achieve ultra-highspeed of up to 8.96 Tb/s on each point-to-point link by utilizing Optical Code Division Multiplexing along with Wavelength Division Multiplexing (OCDMA-WDM) techniques (Medrano et al. 2007). In such high-speed optical networks, the routing algorithm needs to cognizant of the optical signal degradation. Hence, all-optical networks face many challenges due to the transmission impairments in the network physical layer. One of the most important challenges where there has been extensive research is All-Optical Data Routing and Wavelength Assignment (RWA) (Pachnicke et al. 2009, Rahbar 2010).

It is a matter of fact that beyond a certain level of signal degradation, the lightpath cannot be established. Therefore, to ensure high level of service quality, it is essential to setup a path which takes into consideration the impairment effects. In this study, we sharpen the focus on combining the link as well as the node physical impairments between the source and destination nodes and representing them in one metric (cost). Thereafter, the routing algorithm can select the lightpath with high signal quality (Q). This selection is accomplished by choosing a path that corresponds to the lowest metric amongst all computed ones. Consequently, wavelengths and codes can be assigned to each span along the chosen path. Moreover, the selected path has the lowest BER which is related to high Q or OSNR.

The rest of this paper is organized as follow. Section 2 and Section 3 explore the fiber metrics as well as switch metrics computation, respectively, respectively, in terms of their impairments. Simulation results and explanations appear in Section 4. Finally, conclusions will be drawn in Section 5.

2. Fiber metrics computation

As the optical signal from any node in O^3 network traverses a fiber link, it suffers several different types of signal quality degradation. The degradation in the signal is due to optical fiber physical attributes which induce impairments in O^3 networks. In order to take these impairments into account, link properties are converted into a metric matrix.

Here, we assume that each OCDMA-WDM channel within the fiber is identified with two parameters, C_i and λ_j, where they represent optical code and wavelength for each channel, respectively. At any point within the fiber, optical channels can be represented by a metric matrix. Figure 1 shows a span of OCDMA-WDM fiber which has the following characteristics: attenuation α, dispersion D and polarization mode dispersion DPMD. In this figure, the fiber span performs some algebraic operations on the input metric. The results yield out of this operation is calculated as

$$M^{(o)} = M^{(i)} + \Delta \qquad (1)$$

Where $M^{(i)}$ and $M^{(o)}$ denote input and output metric matrices, respectively, and Δ is a fiber metric matrix. The elements of Δ are functions of the link impairments and represent the metric (cost) associated with each OCDMA-WDM channel.

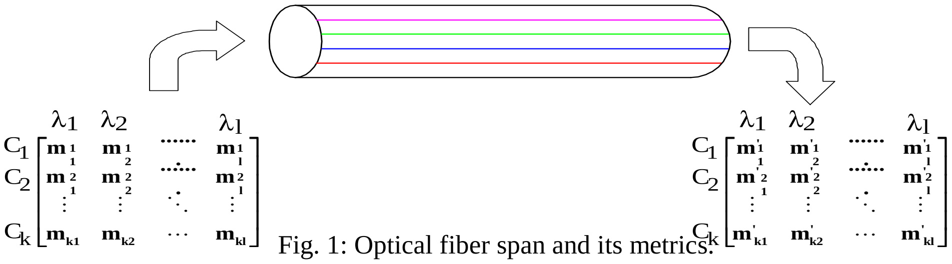

Fig. 1: Optical fiber span and its metrics.

Here, the fiber metrics computation procedure will take into account the linear impairments. This is because linear impairments are predominant than the nonlinear ones. A further study is underway to investigate the effect of nonlinear impairments on fiber metrics. Moreover, different assumptions have been used in metrics computation. These assumptions are: Firstly, all fibers used in the network are single-mode fiber. This assumption eliminates the intermodal dispersion. Thus, linear impairments consist of chromatic dispersion and PMD. Secondly, the fiber used is a dispersion-shifted fiber at 1550 nm window. The last assumption is that attenuation in the C-band is flat, this means that all-optical channels will go under the same attenuation value.

It is worth mentioning that at a given bit rate B, optical fiber characteristics cause significant signal degradation. Signal attenuation and distortion in fiber are the most important degradation factors. By examining these factors, we can easily derive an upper bound for transmission distance (L_{max}) at a given transmission bit rate (B). Advancements in optical fiber manufacturing processes and researches have been made to enlarge fiber link length as well as speed (http://www.hitachi-cable.co.jp/en/ and other websites). In a large link length between optical nodes, an optical amplifier is required to boost the signal power. A lab experiment conducted in (Jackson et al. 2009) shows that the impact of wavelength add-drop transient on the BER for a link with a chain of EDFA's can be reduced by 25%. However, the effect of the other impairments might keep accumulating along the link. Thus, the fiber metric must be adjusted by adding a negative value to take into consideration the effect of the amplifier.

3. Switch metrics computation

Advances in photonic technology have enabled photonic devices to perform their functionality in the optical domain. As a result, reconfigurable photonic switches based on new technology OCDMA-WDM are readily available (Medrano 2005). These all optical switches have full wavelength and code translation capability in the optical domain. Possessing this capability makes the establishment of the lightpath along the link more possible and removes the wavelength continuity constraints.

In all-optical switch, it is very important to understand the various metrics or costs that are related to the switch parameters such as switching time, crosstalk, optical power loss, etc. These metrics can be used to design an optimal routing protocol to improve the overall network performance. The performance analysis can be utilized to define the switch metrics.

The metric matrices on all output ports but the port on which the request has arrived are calculated based on all-optical switch fabric specifications ((Medrano 2005). Needless to say each element in the matrix corresponds to each channel (i.e., code-wavelength combination) within the link. For instance, 2 wavelengths and 2 codes switch's metric matrix can be calculated based on the transmission quality matrix Q (http://www.lanl.gov/lanp/WDM/Gigabit-networking.html). These quality values elements q(i , j) are measured based on BER value that takes place due to the switch characteristics.

$$Q = \begin{array}{c} \\ \lambda_1 C_1 \\ \lambda_1 C_2 \\ \lambda_2 C_1 \\ \lambda_2 C_2 \end{array} \begin{array}{c} \begin{array}{cccc} \lambda_1 C_1 & \lambda_1 C_2 & \lambda_2 C_1 & \lambda_2 C_2 \end{array} \\ \begin{bmatrix} q11 & q12 & q13 & q14 \\ q21 & q22 & q23 & q24 \\ q31 & q32 & q33 & q34 \\ q41 & q42 & q43 & q33 \end{bmatrix} \end{array} \qquad (2)$$

Thus, based on the assumption that the optical fiber is attenuation-limited, Eq. 3 can be used to compute the switch metrics s_{ij}, which are elements of switch metric matrix, as follows.

$$s_{ij} = \left\lceil \left| \frac{10\mathrm{Log}_{10}\left(\frac{q\,(i,\ j)}{\max(q)}\right)}{\alpha} \times \frac{(2^{24}-1)}{L_{atten}} \right| \right\rceil + 1 \qquad (3)$$

Here, $1 \leq i,\ j \leq i \times j$, and the fiber's attenuation factor is α dB/km, and Latten is the maximum span length of the fiber. Therefore the switch metric matrix S (for two wavelengths and two codes) is given by

$$S = \begin{array}{c|cccc|} & \lambda_1 C_1 & \lambda_1 C_2 & \lambda_2 C_1 & \lambda_2 C_2 \\ \lambda_1 C_1 & s_{11} & s_{12} & s_{13} & s_{14} \\ \lambda_1 C_2 & s_{21} & s_{22} & s_{23} & s_{24} \\ \lambda_2 C_1 & s_{31} & s_{32} & s_{33} & s_{34} \\ \lambda_2 C_2 & s_{41} & s_{42} & s_{43} & s_{44} \end{array} \qquad (4)$$

Essentially, the switch matrix, S, shows the penalty of a translation of the wavelength and/or the code into the output port of the switch. For instance, there is a penalty of s_{11} applied when translating $\lambda_1 C_1$ at an input port into $\lambda_1 C_1$ at the output port.

4. Simulation results and explanation

The following example illustrates the process explained in the paper. In this example, we assume that a fiber span installed in a network operates at a bit rate (B) of 2.5 Gbps. For the purpose of fiber metrics computation, the simulation parameters are listed in Table 1.

Table 1: A span of optical fiber specifications.

Parameter	*Value*
Number of wavelengths	2 (1552.53 and 1553.33 nm)
Number of codes	2
Optical bandwidth (B_o)	50 GHz
Electrical bandwidth (B_e)	10 GHz
Signal power per channel	4.77 dBm
Minimum received power (P_{min})	-40 dBm
Other losses (connectors, coupling loss, etc.)	8 dB
$OSNR_{min}$	8.5 dB (BER = 10^{-9})
Fiber effective area (A_{eff})	64 μm^2
Effective fiber length (L_{eff})	22 km
Fiber attenuation (α)	0.2 dB/km
Dispersion slope ($\frac{dD_c}{d\lambda}$)	0.07 ps/km.nm^2
Refractive-index (n)	1.48

Based on the parameters listed in Table 1, the approximate maximum fiber lengths L_{atten} , L_{GVD} and L_{PMD} are 178.85, 4.48×10^3, and 1.6×10^5 km, respectively.

Figure 2 shows the calculated metrics at different fiber lengths (L) when the network operates at bit rate B of 2.5 Gbps and wavelength of 1552.5nm. In Figure 3, one can see that if the fiber length exceeds 178.85 km, the metric value equal to 16.777×10^6 (which is the K value). Thus, the lightpath is impassable.

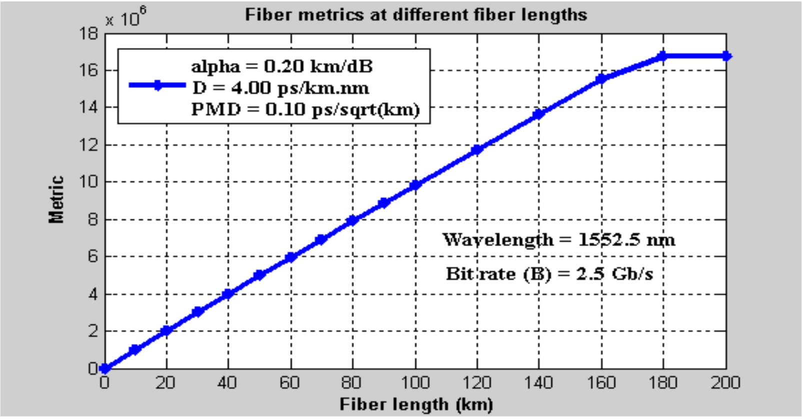

Fig. 2: Metrics computation for a fiber link based on specifications listed in Table 1.

Given the linear and non-linear effects of optical components used in the switching architecture, all-optical switch metric based on BER is defined. To measure the effects of all-optical switch on BER, we assume that the switch is fully loaded. A close estimation of the BER performance of an optical system given the mean and standard deviation for the peak pulse and noise level is presented in (Medrano et al. 2007). In addition, the Q factor is computed for different interconnection module configurations of the switch. The switch has four entry ports (2x2). Each port is populated by 2 wavelengths (λ_1 = 1552.2nm and λ_2 = 1551.99nm) and 2 codes (i.e., four channels).

Figure 3 displays the Q factors for four different interconnection module configurations, which are presented in ((Medrano 2005). Observing the Q factor, it demonstrates that the optimal BER is affected by frequency conversion, and changes in the encoding sequence do not affect the BER rate performance.

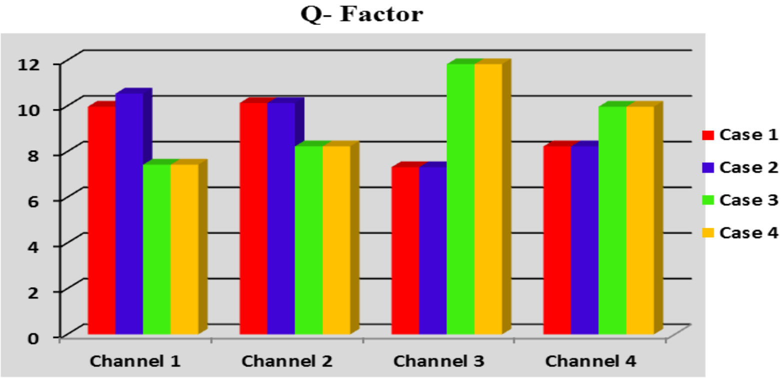

Fig. 3: Q-factor of four different O3 switch configurations.

Now, the switch metric can be computed using Eq. 3

$$S = \begin{array}{cc} & \begin{array}{cccc} \lambda_1C_1 & \lambda_1C_2 & \lambda_2C_1 & \lambda_2C_2 \end{array} \\ \begin{array}{c} \lambda_1C_1 \\ \lambda_1C_2 \\ \lambda_2C_1 \\ \lambda_2C_2 \end{array} & \begin{bmatrix} 358 & 324 & 1000 & 757 \\ 242 & 324 & 1000 & 757 \\ 970 & 757 & 1 & 358 \\ 970 & 757 & 1 & 358 \end{bmatrix} \end{array}$$

In the light of the computed metrics, the O^3 Data Routing and Wavelength along with Code Assignment (RWCS) algorithm can determine the best possible path from the source to destination. The best path is chosen by applying the minimum function to select the minimum metric amongst all received matrices at the destination. This minimum metric corresponds to each wavelength-code combination (Shadaram et al. 2007).

5. Conclusions

Combining wavelength and code multiplexing techniques generates an all-optical circuit-switched network with a huge volume of data capacity. In such unparalleled high-speed network, setup a lightpath between two nodes within becomes more complex. The complexity arises as the wavelength and code are assigned on a predetermined path between the two nodes based on some cost metrics. These metrics represent the physical layer impairments of O^3 networks that impose a great effect on each individual OCDM-WDM channel.

There are two types of metrics in O^3 networks: Transmission medium metrics matrix and node metrics matrix. These matrices are calculated based on the link and node impairments. An investigation has been conducted here to show the effect of O^3 network's impairments on the signal quality (Q). The most suitable criterion to evaluate Q in O^3 network is the optical signal-to-noise ratio (OSNR), which is a major contributor to bit error rate (BER).

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Ahmed Musa was born on October 20, 1974 in Irbid, Jordan. He received a B.S. and M.S. in 1997 and 2000, respectively, in electrical and computer engineering from Jordan University of Science and Technology, Irbid, Jordan. He worked as a telecom engineer in Jordan Telecom from 1999-2001. In the fall of 2001, he joined the Ph.D. program in Computer Engineering at the University of Texas at El Paso. While his period at UTEP, Musa worked at the Fiber Optic modeling and simulation Laboratory as a Research Assistant from 2004 to 2006. He also was appointed as instructor at UTRP from 2003 to 2006. In 2006, Musa joined the faculty of Computer Engineering at Al-Hussein Bin Talal University (AHU), Ma'an – Jordan. In the fall of 2006, Musa is charged with leading the Department of Computer Engineering at AHU to the next level of distinction and assisting the college of Computer Engineering and Information Technology in promoting excellence in research and teaching. In 2007, Musa received the AHU Award for his great academic achievement and his research. In fall 2011, Musa was promoted to an associate professor rank. Currently, he is on unpaid leave from Department of Computer Engineering, AHU and works at Department of Computer Engineering, Taif University, Kingdom of Saudi Arabia.

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