Journal of the Optical Society of Korea, Vol. 11, No. 1, March 2007, pp. 6-9

A Wavelength Allocation Method for Bidirectional Transmission in a CWDM Channel

Jung-Hyung Moon*, Ki-Man Choi, and Chang-Hee Lee

Department of Electrical Engineering and Computer Science, Korea Advanced Institute of Science and Technology, 373-1 Guseong-dong, Yuseong-gu, Daejeon, 305-601, Korea

(Received December 12, 2006 : revised December 14, 2006)

We propose a wavelength allocation method for bidirectional transmission in a coarse wavelength division multiplexing channel. The method can be accommodated by assigning a different upstream wavelength from the downstream wavelength at room temperature to eliminate penalties induced by backscattering, including Rayleigh backscattering. We suggest a procedure to obtain the minimum wavelength difference.

OCIS codes : 060.4250, 060.4510, 290.1350, 290.5870

I. INTRODUCTION

COARSE wavelength division multiplexing (CWDM) is an attractive choice for realizing a cost-effective WDM system because it uses directly modulated uncooled laser diodes (LDs) and cost-effective CWDM filters based on thin film filter technology. The ITU-T standards G.694.2 and G.695 specify a CWDM system of up to 18 channels with 20 nm spacing between 1271 nm and 1611 nm.

The cost of the system can be reduced with bidirectional transmission because it reduces the transmission fiber and the CWDM filter. In a general bidirectional system, the upstream and the downstream channels are allocated to different wavelengths. The maximum number of channels in one direction then falls to 9 when we assign the different CWDM channels for the opposite direction. To maintain the number of channels at 18 in both directions, we therefore need to allocate two wavelengths in each CWDM band. However, backscattering, including Rayleigh backscattering (RB), severely degrades the transmission performances [1-3].

In this paper, we propose a wavelength assigning method for a high capacity bidirectional CWDM system that can accommodate 18 channels in one direction. To investigate the feasibility of the proposed method, we examined the effects of RB in relation to the signal to backscattering power ratio (SBR) and the wavelength difference between the upstream and downstream sources. We also investigated the required wavelength difference between the upstream and downstream sources at room temperature to eliminate the penalties induced by the RB. Furthermore, our application of the proposed method in several regions of South Korea confirms the feasibility of the bidirectional CWDM system.

II. WAVELENGTH ALLOCATION METHOD

Figure 1 shows the proposed wavelength allocation method for the bidirectional CWDM system. To avoid the effects of RB, we used different wavelengths for the upstream and downstream sources in each CWDM channel. The wavelength of the upstream source is shorter than the wavelength of the downstream source, but the two wavelengths can be positioned opposite each other. Guard bands are also needed on the edges of both sides. We defined the wavelength variations of the upstream source in the optical network unit (ONU) as $\triangle\lambda_{ONU}$ and those of the downstream source in the central office (CO) as $\triangle\lambda_{CO}$. The total bandwidth for the upstream, the downstream and the guard bands must be within the bandwidth of a CWDM filter (λ_{BW}).

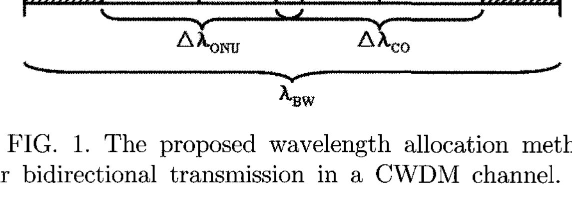

FIG. 1. The proposed wavelength allocation method for bidirectional transmission in a CWDM channel.

In addition, we defined the wavelength difference between the upstream and the downstream at room temperature as $\triangle\lambda_B$. As we decrease the $\triangle\lambda_B$, there is an increased probability of the upstream wavelength coinciding with the downstream wavelength. The RB-induced penalties are also likely to become higher. Furthermore, the possibility of the wavelengths being outside the range of a CWDM band, if $\triangle\lambda_B$ is too large highlights the importance of selecting a suitable value for $\triangle\lambda_B$.

The requirements of wavelength allocation for bidirectional transmission in a CWDM channel can be expressed as

$$\iint P\left[\left|\lambda_{ONU}(T_{ONU}) - \lambda_{CO}(T_{CO})\right| \geq \Delta\lambda_D(B, SBR)\right] dT_{ONU}\, dT_{CO} \geq P_{st} \quad (1)$$

$$\Delta\lambda_B = \left|\lambda_{ONU}(25°C) - \lambda_{CO}(25°C)\right|, \quad (2)$$

where $\lambda_{ONU}(T_{ONU})$ is the wavelength of the upstream source at temperature T_{ONU} and $\lambda_{CO}(T_{CO})$ is the wavelength of the downstream source at temperature T_{CO}. We can then use the experimental results to determine the SBR and the required wavelength difference between the upstream and downstream sources, $\triangle\lambda_D$(B, SBR), for avoiding the effects of RB for a given bit rate (B). For a bidirectional transmission system without an amplifier, we can express the SBR at the receiver in dB as

$$SBR = -L - R - \Delta P, \quad (3)$$

where L is the fiber loss in dB; R is the backscattering reflectivity, the typical value of which is around -32 dB; and $\triangle P$ is the power difference between the upstream and the downstream sources in dB [4]. With the availability of the system (P_{st}) specified in the range of 99.99% (53 minutes for one year) to 99.999% (5 minutes for one year), we can determine the minimum wavelength difference, $\triangle\lambda_B$, for the given values of P_{st} and $\triangle\lambda_D$(B, SBR).

III. THE EFFECTS OF RAYLEIGH BACKSCATTERING

To obtain the values of $\triangle\lambda_D$(B, SBR), we investigated the effects of RB. Figure 2 shows the experimental setup for examining RB-induced impairments. We used distributed feedback laser diode (DFB-LD) 1 as the signal source, and DFB-LD 2 to generate the RB signal. The two LDs were directly modulated at 2.5 Gb/s with a 2^{31}-1 pseudorandom sequence. The extinction ratio was 11 dB for LD 1 and 9.5 dB for LD 2. After we amplified the output of LD 2 with an erbium-doped fiber amplifier (EDFA), the output passed through an optical circulator and a 40 km single-mode fiber (SMF). We then obtained the RB signal by using the circulator as an interference signal for the signal from LD 1. In addition, by using two polarization controllers (PCs), we were able to adjust the polarization state of the signal and the RB signal. The degree of polarization (DOP) of the RB signal was 33% [5]. Next, we used a polarization beam splitter (PBS) to monitor the relative polarization states of the signal and the RB signal. All our experimental results are based on the worst case scenario: that is, we matched the polarization of the two interfering signals in order to maximize the interference. We also used a variable optical attenuator (VOA) to change the SBR. We maintained the wavelength of LD 1 by using a thermoelectric cooler (TEC) controller, and we changed the wavelength of LD 2 to examine how the wavelength difference affected the RB-induced penalty. In addition, we used a multi-wavelength meter (with an accuracy of 0.003 nm) to measure the wavelengths of LD 1 and LD 2.

Figure 3 shows the measured power penalties at the bit error rate (BER) of 10^{-9} as a function of the wavelength difference at the SBR of 14 dB. The highest penalty occurs when the wavelength difference between the two LDs is zero. And the power penalties rapidly decrease when the wavelength difference is less than

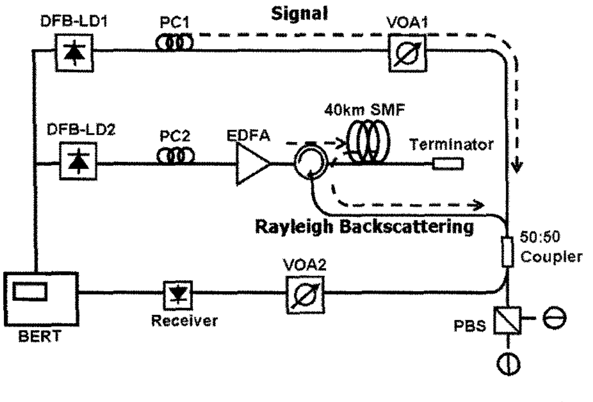

FIG. 2. Experimental setup for investigating the effects of Rayleigh backscattering.

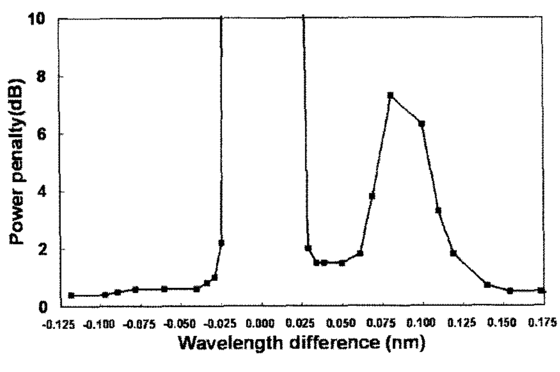

FIG. 3. The measured power penalties in relation to the wavelength difference at 14 dB of the SBR.

-0.025 nm (-3 GHz) or greater than 0.025 nm (3 GHz). These trends are similar to the results obtained by using external modulation [6-7]. The impairments at around 0.085 nm of the wavelength difference result from a beating noise between the peak wavelength of the RB signal and the adiabatic chirp component of the signal. Note, however, that the position of the adiabatic chirp depends on the laser by laser. As shown in Fig. 4, we also measured the power penalties in relation to the SBR. The solid markers represent the power penalties at a wavelength difference of 0 nm, while the hollow markers represent the power penalties at a wavelength difference of 0.085 nm.

On the basis of the experimental results in Fig. 3 and Fig. 4, we estimated the required minimum wavelength difference, $\triangle\lambda_D$(B, SBR). We assumed an acceptable system penalty of 1.5 dB. Figure 5 shows the results as a function of the SBR or the fiber loss when the power difference of the upstream transmitter and the down stream transmitter is 5 dB. When the SBR is higher than 22 dB (that is, the fiber loss is smaller than 5 dB), we can use the same wavelength for both the upstream and the downstream sources. Hence, $\triangle\lambda_D$ is 0 nm. The penalty increases rapidly when the two wavelengths are the same and the SBR is less than 22 dB. In that situation, we cannot use the identical wavelength and the two wavelengths must be different. When the SBR is 16 dB, the power penalty is 1.5 dB at a wavelength difference of 0.085 nm. Therefore, $\triangle\lambda_D$ is about 0.025 nm (that is, 1.2 * the bit rate) until the SBR reaches 16 dB [6-7]. For an SBR of less than 16 dB, $\triangle\lambda_D$ rapidly increases; and $\triangle\lambda_D$ is about 0.125 nm when the SBR is 14 dB.

IV. APPLICATION IN SEVERAL REGIONS OF SOUTH KOREA

On the basis of previous results, we applied the proposed method to several regions of South Korea. We selected the following four regions of South Korea in 2004: region 1, the capital city; region 2, an oceanic climate; region 3, the coldest area; and region 4, the hottest area. In these areas, the temperature varied from -20℃ to 40℃. By using $\triangle\lambda_D$ and the temperature distribution of these regions, we calculated the minimum values of $\triangle\lambda_B$. To do that, we made several assumptions. First, we assumed uncontrolled CWDM sources with a temperature tuning coefficient of 0.1 nm per 1℃. Second, we uncorrelated the upstream and downstream sources for the worst case scenario. Whenever the upstream wavelength became dependent on the downstream wavelength, the minimum $\triangle\lambda_B$ diminished.

For a fiber loss of less than 5 dB, $\triangle\lambda_B$ is 0 nm because $\triangle\lambda_D$ is 0 nm. For a fiber loss between 5 dB and 11 dB, we used equation (2) to calculate the fault time for the year in relation to $\triangle\lambda_B$. Figure 6 shows the results. To satisfy the probability of the 99.99% requirement for the access network, $\triangle\lambda_B$ must be higher than 3 nm to 4 nm, depending on the region. We found that $\triangle\lambda_B$ is about 4 nm to 4.5 nm for a fiber loss larger than 11 dB.

When $\triangle\lambda_B$ is 4.5 nm and the temperature is distributed between -15℃ and 40℃, as in region 1, we can realize the bidirectional CWDM system with a conventional CWDM filter with a bandwidth of 13 nm at a guard band of 1.5 nm on each side ((13-5.5-4.5)/2=1.5 nm).

Because the DOP of the RB is 33%, penalty increases are induced whenever the same amount of

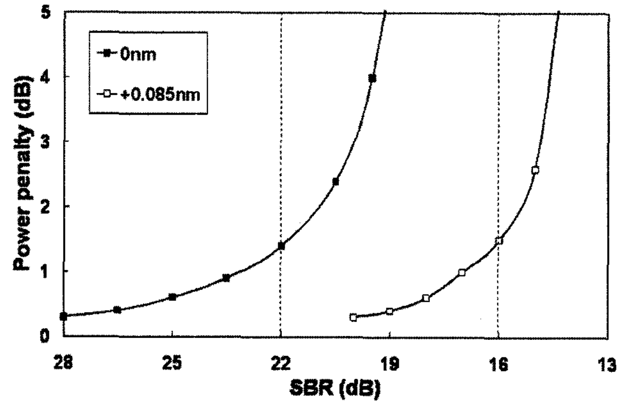

FIG. 4. The measured power penalties in relation to the SBR at wavelength differences of 0 nm and 0.085 nm.

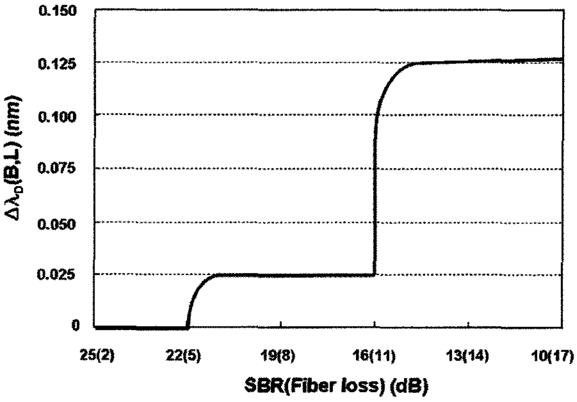

FIG. 5. Comparison of $\triangle\lambda_D$ versus the SBR and fiber loss when the bit rate is 2.5 Gb/s and the power ratio is 5 dB.

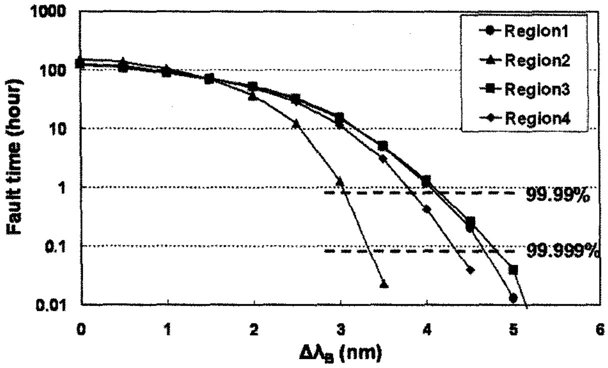

FIG. 6. Fault time during one year versus $\triangle\lambda_B$ when the bit rate is 2.5 Gb/s and the SBR is 16~22 dB.

reflection from multiple points has a polarization state that is identical to the signal. The allowable fiber loss then decreases by 1.8 dB at the same SBR [8-9].

V. CONCLUSION

We have proposed a wavelength allocation method for a high capacity bidirectional CWDM transmission. By applying the proposed method, we can select the upstream and downstream wavelengths at room temperature to accommodate a maximum of 18 bidirectional CWDM channels in both directions. For our application in South Korea, we also obtained the required minimum wavelength difference between the upstream and the downstream at room temperature ($\triangle\lambda_B$) for a 2.5 Gb/s transmission.

ACKNOWLEDGEMENT

This work was supported by the National Research Laboratory under the aegis of the Korean Ministry of Science and Technology.

*Corresponding author: chl@ee.kaist.ac.kr

REFERENCES

[1] T. H. Wood, R. A. Linke, B. L. Kasper, and E. C. Carr, "Observation of coherent Rayleigh noise in single-source bidirectional optical fiber systems," *J. Lightwave Technol.*, vol. 6, no. 2, pp. 346-352, 1988.

[2] R. K. Staubli and P. Gysel, "Crosstalk penalities due to coherent Rayleigh noise in bidirectional optical communication systems," *J. Lightwave Technol.*, vol. 9, no. 3, pp. 375-380, 1991.

[3] E. L. Goldstein, L. Eskildsen, and A.F. Elrefaie, "Performance implications of component crosstalk in transparent lightwave networks," *IEEE Photon. Technol. Lett.*, vol. 6, no. 5, pp. 657-660, 1994.

[4] S. K. Das and E. E. Harstead, "Beat interference penalty in optical duplex transmission" *J. Lightwave Technol.*, vol. 20, no. 2, pp. 213-217, 2002.

[5] M. O. van Deventer, "Polarization properties of Rayleigh backscattering in single-mode fibers," *J. Lightwave Technol.*, vol. 11, no. 12, pp. 1895-1899, 1993.

[6] S. Radic and S. Chandrasekar, "Limitations in dense bidirectional transmission in absence of optical amplification," *IEEE Photon. Technol. Lett.*, vol. 14, no. 1, pp. 95-97, 2002.

[7] M. Sumida, T. Kubo, and T. Imai, "Limitations imposed by Rayleigh backscattering in closely interleaved, bidirectional WDM transmission systems," *IEEE Photon. Technol. Lett.*, vol. 15, no. 1, pp. 150-152, 2003.

[8] M. Oskar van Deventer, "Power Penalties Due to Reflection and Rayleigh Backscattering in a Single Frequency Bidirectional Coherent Transmission System," *IEEE Photon. Technol. Lett.*, vol. 5, no. 5, pp. 851-854, 1993.

[9] C. J. Rasmussen, Liu Fenghai, R.J.S. Pedersen, and B.F. Jorgensen, "Theoretical and experimental studies of the influence of the number of crosstalk signals on the penalty caused by incoherent optical crosstalk," in Proc. OFC 99, *Optical Society of America*, San Diego, USA, Paper TuR5, pp. 258-260, 1999.