Performance Enhancement of Optical Fiber Communication Systems using Convolution Codes

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ABSTRACT

The power depletion in the short wavelength channels due to Stimulated Raman Scattering (SRS) impairs the system performance considerably and very often the desired Bit Error Rate (BER) is not attainable. This problem is usually countered by placing optical amplifiers in the link to maintain the required BER performance. Also, impact of crosstalk in N x N WDM systems causes high noise power. In this paper we theoretically demonstrate, as one of the methods, the improvement in performance of WDM systems in the presence of SRS and beat noise using convolution codes for forward error correction. We have shown that the use of error control coding technique improves the system performance while keeping the power penalty below 1dB at BER of 10^{-9}. We found that even with more than 140 users, with coding, detector can effectively receive required power in SRS limited WDM systems for link length of 200km. Our results also show that the multiplexer crosstalk effectively comes down from -34dB to -44dB with coding for beat noise limited power penalty of 1dB.

Key words: Nonlinear effects, Stimulated Raman Scattering (SRS), Wavelength Division Multiplexing (WDM), Bit Error Rate (BER), Channel Beat Noise and Error control coding.

1. Introduction

The nonlinear effects in optical fibers are an area of active research. To enhance the data carrying capacity, WDM is invariably used in long haul optical communication systems. The SRS [1-4] and crosstalk [5] limits the performance of a WDM system. SRS causes power to be transferred from shorter wavelength channels to the longer wavelength channels. The power depletion converges to a Gaussian random variable [6].

The performance degradation due to incoherent crosstalk has been studied and shown that incoherent crosstalk may cause fluctuation of signal power [4], [7] because it can be a coherent combination of crosstalk contributions. In presence of crosstalk, in N wavelength N x N optical interconnection system, the multiplexer crosstalk must be less than -34dB for N=17 for BER performance of less than 10^{-9} for power penalty of 1dB [9]. We have shown that the use of error control coding technique improves its performance while keeping the power penalty below 1dB at BER of 10^{-9}. Also shown that in presence of beat noise in WDM systems, with the introduction of error control coding, the limit on multiplexer crosstalk will become more flexible than what it was earlier.

2. WDM Systems with SRS

The estimation of SRS threshold with linear Raman gain profile is studied in [2]. As shown in Figure 1, with responsivity 1A/W, shot and thermal noise current of mean value 10nA and 100nA respectively, to maintain a BER of 10^{-9} the PIN receiver needs at least 0.6μW (-32.21dBm). The parameters used in calculations are peak Raman gain coefficient of 7×10^{-14}m/W, effective fiber length of 21.7km, effective fiber area of 50μm^2 and attenuation coefficient of 0.2dB/km. Fig.2 shows the variation of power with respect to the number of channels so as not to cause more than 1dB of power depletion for three different values of channel spacings. With power penalty of less than 1dB, the required power of 0.6μW is received at 200km distance only with 47,

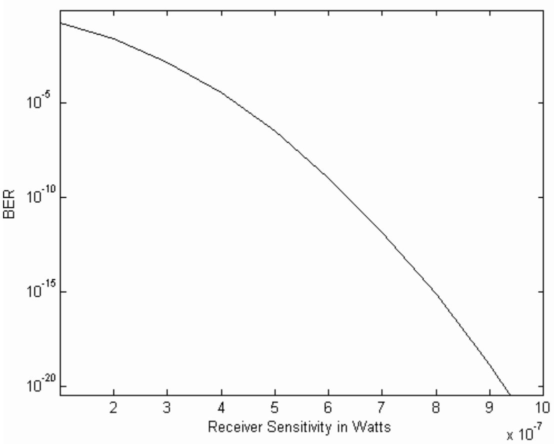

Fig.1: BER as a function of receiver sensitivity.

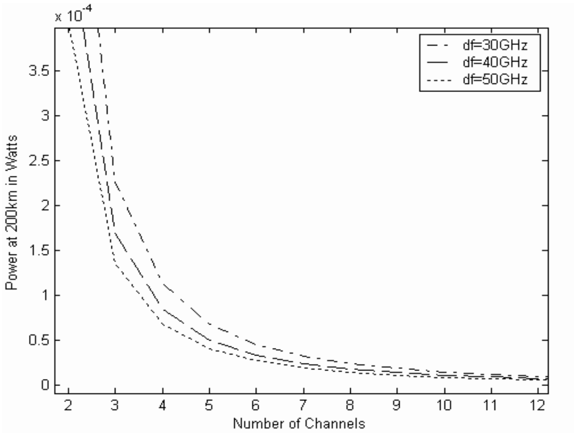

Fig.2: Power at 200 km fiber length decreases with channel spacing so that SRS power penalty is less than 1dB.

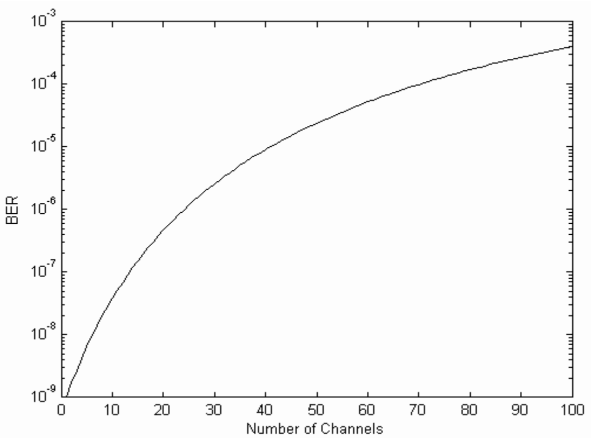

Fig.3: BER as a function of number of channels in presence of beat noise.

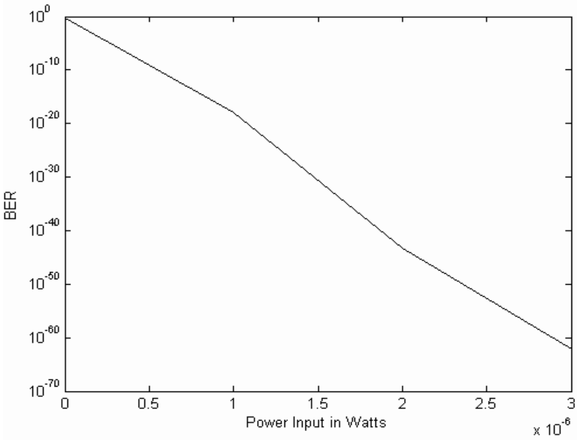

Fig.4: BER as a function of injected power in presence of channel beat noise.

40 and 37 channels with 30, 40 and 50GHz spacing respectively.

3. WDM System with Beat Noise

The impact of crosstalk in an N x N WDM system has been studied in [5], [9] and the beat noise has been approximated to be of Gaussian distribution. In presence of beat noise, with thermal noise current of 100nA and shot noise of 10nA, the deterioration in BER with respect to the number of channels is shown in Fig.3 and the variation of input power with BER in presence of beat noise for multiplexer crosstalk of -34dB for 16 crosstalk components is shown in Fig.4. From Fig.3 it can be shown that required BER of 10^{-9} can be achieved only for one user. As shown in Fig.4 the minimum power required by the receiver to maintain BER of 10^{-9} in the presence of beat noise is 0.5µW.

4. Convolution Coding

A convolution code is generated by combining the outputs of M-stage shift register with prescribed connections to ‘n’ modulo-2 adders [10]. A K bit message sequence produces a coded output sequence of length n (K+M) bits having code rate of (1/n) bits/symbol. The Viterbi decoding algorithm [11] is a maximum-likelihood decoder for an AWGN channel. Here we have considered, for example, a convolution encoder with rate ½ and M=3 for a binary symmetric channel having symmetric transition probabilities.

5. RESULTS AND DISCUSSIONS

The enhancement of performance with Convolution coding SRS power penalty of not more than 1dB is shown in Fig. 5

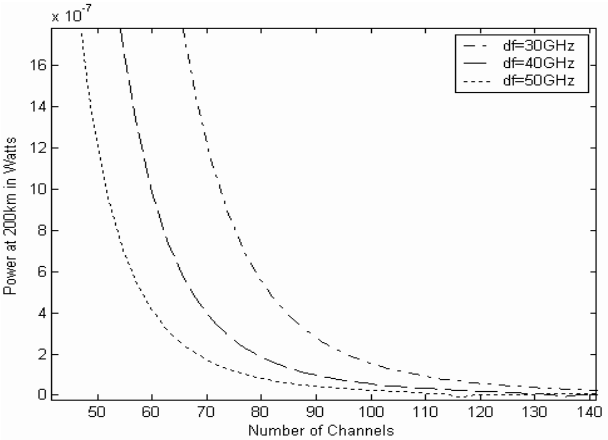

Fig.5: Availability of power at 200km distance fiber increses with respect to the number of channels with coding.

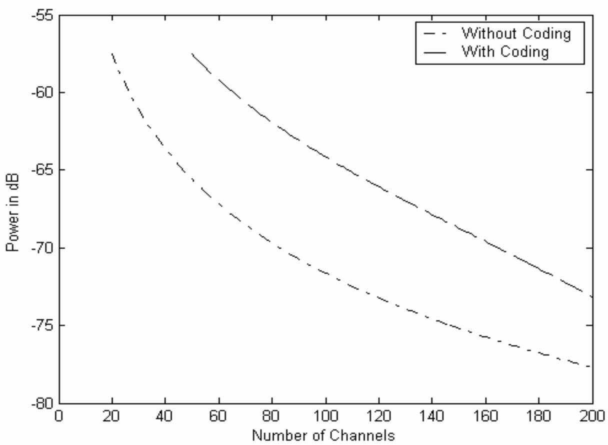

Fig.6: More power effectively available with coding.

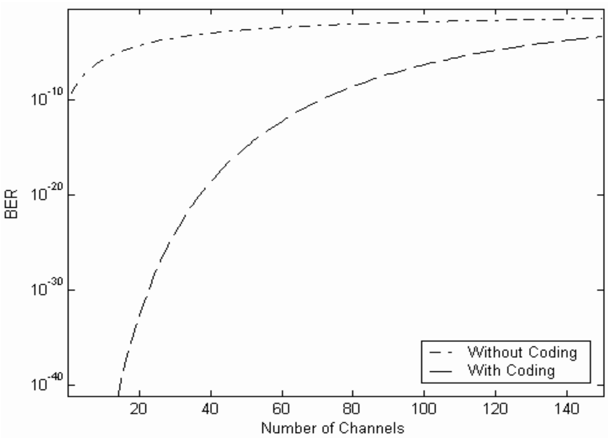

Fig.7: BER as a function of number of channels in presence of beat noise with and without coding.

The required power of 0.6μW is available effectively at 200km distance for 78, 66 and 56 channels with channel spacing of 30, 40 and 50GHz respectively so as to keep SRS power to less than 1dB with coding as shown in Fig. 5. This shows considerable improvement when compared to that of shown in Fig. 2. The amount of increase in power is around 2dB can be achieved with coding as shown in Fig. 6. In presence of beat noise, BER of 10^{-9} can be achieved up to 106 users with coding as shown in Fig. 7. At BER of 10^{-9}, the multiplexer crosstalk effectively reduces to -44dB with coding instead of -34dB without coding for power penalty of 1dB for 16x16 network as shown in Fig. 8.

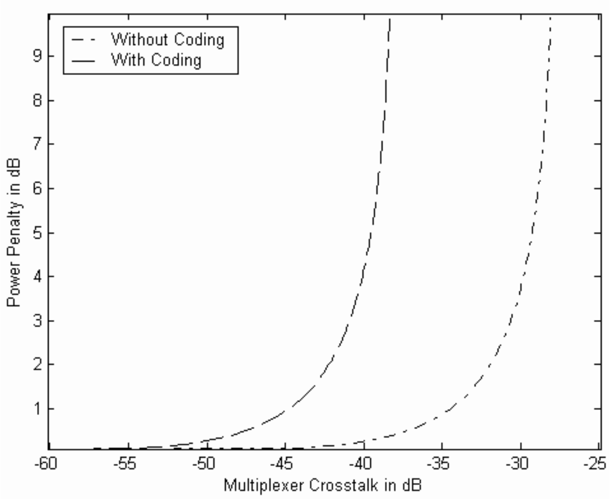

Fig.8: Power penalty as a function of multiplexer crosstalk with and without coding at BER of 10^-9.

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