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Analysis the Performance of Coded WSK-DWDM Transmission System

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ABSTRACT

Dense Wavelength Division Multiplexing (DWDM) is the system with more than eight active wavelengths per fiber. Again high data rates as well as long spans between amplifiers in a chain require high optical power per channel to satisfy the signal to noise ratio (SNR) requirements. So the DWDM systems with long repeater-less spans, the simultaneous requirements of high launched power and low dispersion fibers lead to the generation of new waves by four-wave mixing (FWM), which degrades the performance of a multi-channel transmission system. Several methods have been proposed to mitigate the effect of FWM crosstalk. All these works are performed considering only binary WSK scheme. Although M-ary WSK (M>2) schemes have higher spectral efficiency than binary WSK system. Again, the BER performances for M-ary WDM system are not satisfactory with the effect of FWM. Therefore, in this paper we include the effect of FWM on the performance of an M-ary WDM system and try to mitigate the effect by employing the energy efficient convolution code in a normal dispersive fiber as well as in a dispersion shifted fiber (DSF).

Keywords: *Dense Wavelength Division Multiplexing (DWDM); four-wave mixing (FWM); dispersion shifted fiber (DSF; signal to noise ratio (SNR); bit error rate (BER); Multiple Ary(M-ary).*

1. INTRODUCTION

Communication is the process of transferring information or message like voice, video, text, data, picture, etc. from one distance to another. The function of communication system is to convey the signal from the information source over the transmission medium to the destination. In general, the information carrying capacity should be high so that it can meet the requirement of the user. The information carrying capacity is closely related to the bandwidth supported by the communication system. The greater the bandwidth, the higher is the information carrying capacity of the communication system. In this respect optical fiber communication system has been developed. The huge potential bandwidth of optical fiber can be afficiently utilized by multiplexing a number of channels and transmitting them through the fiber simultaneously. The transmission bandwidth of fiber is divided into a number of nonoverlapping frequency (or wavelength) bands and each of these bands is associated to support a single communication channel. Two principle kinds of multichannel systems are common in practical applications, namely, frequency division multiplexing (FDM) and wave length division multiplexing (WDM). The two schemes differ from each other in respect of transmitter/receiver configuration.

Optical dense wavelength division multiplexing (DWDM) systems using low dispersion fibers and erbium-doped fiber amplifier (EDFA) are very attractive to meet up the growing demand for broadband information distribution networks. A large number of wavelength channels, operating at 10 Gb/s, can be multiplexed at several gigahertz intervals if fiber low dispersion region around 1.55µm (~ 12.5 THz bandwidth) is fully utilized [1-3]. For DWDM systems with long repeater-less spans, the simultaneous requirements of high launched power and low dispersion fibers lead to the generation of new waves by four-wave mixing (FWM) [4-5]. The FWM is the dominant nonlinear effect that severely degrades the performance of a multi-channel transmission system. Several methods have been proposed to mitigate the effect of FWM crosstalk, namely, arrangement of transmission fiber dispersion, unequal channel spacing (US) scheme, repeated unequal channel spacing (RUS) scheme, wavelength Shift Keying (WSK) [6-8]. The improvement of WSK-WDM system relative to conventional on-off wavelength division multiplexing (WDM) system has been studied [8]. The works on WSK-WDM considered only binary WSK although M-ary WSK (M>2) schemes have higher spectral efficiency than binary WSK system. In the above research works, the BER performance for M-ary uncoded WDM system performance has not been considered while mitigating the effect of FWM. It is, therefore, very much important to include the effect of FWM as the performance of a M-ary WDM system is highly dependant on the interplay between the cross-phase modulation and four-wave mixing in a normal dispersive fiber as well as in a dispersion shifted fiber (DSF) [9-11].

2. SYSTEM MODEL

The model of the WSK-DWDM system considered for analysis is shown in Fig 1. The system is used to combine different signal carrier wavelengths onto a single fiber at one end and separate them onto their corresponding detectors at the other end. The Encoder encoded the data and at the receiving end the decoder decoded that data to received same signal. The convolution coding is used in this system. Here MUX combine all of the signals and create a composite signal. This signal passes through the optical fiber and optical amplifier. Optical amplifier amplifies an optical signal directly, without the need to first convert it to an electrical signal. An optical amplifier may be thought of as a laser without an optical cavity, or one in which feedback from the cavity is suppressed. Stimulated emission in the amplifier's gain medium causes amplification of incoming light and DMUX separate them.

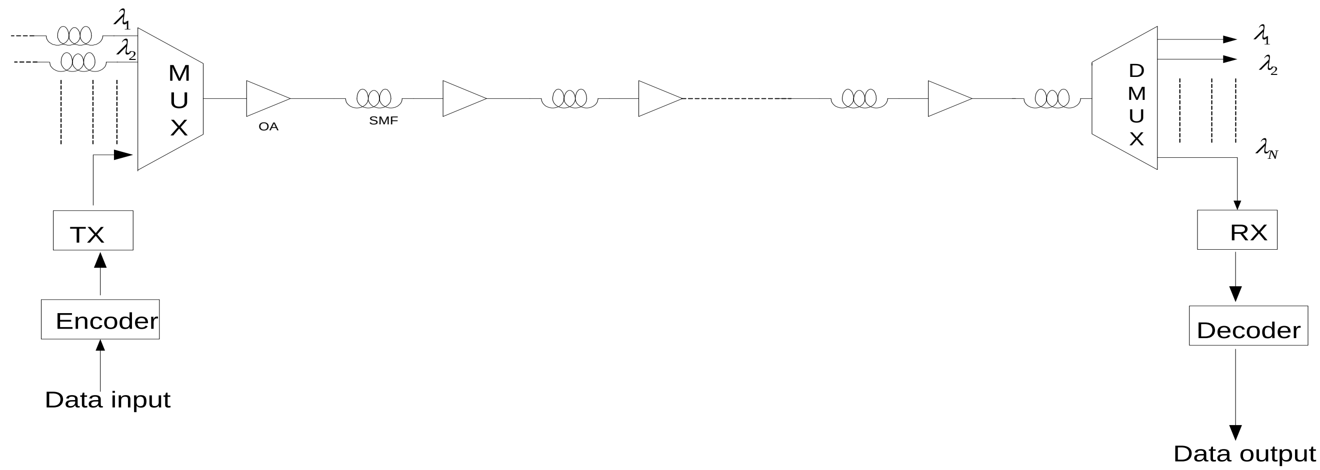

Fig. 1. Block diagram basic coded WSK-WDM transmission system.

Then at the receiver we get all the signals individually. In orthogonal MWSK, the M=2k district symbols are represented by M-WSK waveforms

$$S_m(t) = ACos(W_m t + \phi_m), \text{ where, } m = 1, 2,..,M \quad (1)$$

where

$$W_m = 2\pi f_m = \frac{2\pi C}{\lambda_m}$$

ϕ_m = initial phase

A = Signal amplitude

$T_s = KT_b$ = Signaling interval

T_b = bit duration

$E_s = \frac{A^2 T_s}{2}$ = Signal Energy = Energy/symbol

To derive the average probability of symbol error, we assume that the signal (S, H) was sent and received signal

$$r(t) = S_1(t) + n(t) \quad (2)$$

Where,

n(t)=AWGN with zero mean.

$S_1 = E_S + n_1$

$S_m = n_m$,m=2,3……..M

$$n_m = \int_0^{T_s} n(t) S_m(t) dt \quad (3)$$

3. CHANNEL MODELLING

With the increase of data rates on optical fiber, transmission length, number of channels and optical power levels, non linear effects of fiber becomes dominant. The huge potential bandwidth of optical fiber can be afficiently utilized by multiplexing a number of channels and transmitting them through the fiber simultaneously. The transmission bandwidth of fiber is divided into a number of nonoverlapping frequency (or wavelength) bands and each of these bands is associated to support a single communication channel. Two principle kinds of multichannel systems are common in practical applications, namely, frequency division multiplexing (FDM) and wave length division multiplexing (WDM). The two schemes differ from each other in respect of transmitter/receiver configuration. The probability density function of S_m, given that S_1 (t) was sent is

$$P\left(\frac{S_m}{S_1}\right) = \frac{e^{-\frac{[(S_m - \delta_{1m} E_s)^2}{E_s N_0}}}{\sqrt{\Pi E_s N_0}} \quad (4)$$

Now,

$$\int_{-\alpha}^{S_1} P\left(\left(\frac{S_M}{S_1}\right) dS_M\right) = 1 - \int_{S_1}^{\alpha} \frac{e^{-\frac{S_M^2}{E_S N_0}}}{\sqrt{\pi E_S N_0}} dS_M \qquad (5)$$

$$let, x = \sqrt{\frac{2}{E_s N_0}} S_M$$

$$\int_{-\alpha}^{S_1} P\left(\frac{S_M}{S_1} dS_M\right) = 1 - \int_{\sqrt{\frac{2}{E_S N_0 S_1}}}^{-\alpha} \frac{e^{-\frac{x^2}{2}}}{\sqrt{2\pi}} dx \qquad (6)$$

The performance of a multichannel WSK-WDM transmission system in presence of FWM has been evaluated in this section for binary and M-ary system. The system performance depends on various system parameters such as transmission power per channel, number of channel, fiber length; different channel spacing will be examined. Finally, the performance of WSK-WDM system is compared for binary and M-ary uncoded system with different parameters.

4. THEORETICAL ANALYSIS

$$P_{e_1} = 1 - \int_{-\alpha}^{\alpha} \left[1 - \varphi\left(\sqrt{\frac{2}{E_S N_0}} S_1\right)\right]^{M-1} \frac{e^{-\frac{(S_1 - E_S)^2}{E_S N_0}}}{\sqrt{\pi E_S N_0}} ds \qquad (7)$$

$$P_{e_1} = 1 - \frac{1}{\sqrt{2\pi}} \int_{-\alpha}^{\alpha} \left[1 - \varphi\left(y + \sqrt{\frac{2E_S}{N_0}}\right)\right]^{M-1} e^{\left(\frac{-y^2}{2}\right)} dy \qquad (8)$$

$$P_{e_1} = 1 - \frac{1}{\sqrt{2\pi}} \int_{-\alpha}^{\alpha} \left[1 - \varphi\left(y + \sqrt{\frac{2E_S \log_2 M}{N_0}}\right)\right]^{M-1} e^{\left(\frac{-y^2}{2}\right)} dy \qquad (9)$$

$$\text{Let,} \quad y_1 = 1 - Q\left(y + \sqrt{\frac{2E_s}{N_0}}\right)^{M-1} = 1 - Q\left(y + \frac{R_d P_s}{\sigma_0}\right)^{M-1} \qquad (10)$$

We can write, the probability of BER for WSK-WDM system,

$$P_{e1} = 1 - \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} [1 - Q(y + \frac{R_d P_S}{\sigma_O})]^{M-1} e^{(\frac{-y^2}{2})\, dy} \qquad (11)$$

4.1 Bit Error Rate (BER) of Uncoded System

In the transmitter, the data of 10 Gbps is used to directly modulate a laser to generate the WSK signal which is transmitted through a single-mode fiber. At the receiving end, the received optical signal is detected by a Mach-Zehnder interferometer.

In the WSK direct detection receiver with MZI, the MZI act as an optical filter and differentially detect the 'mark' and 'space' of received WSK signal. The 1st MZI received the multiple channel signals then it differentially detects the odd and even signals. Those are then directly fed to a pair of MZIs. The 'Odd' signals go to one MZI and the even signals go to another MZI. After that the signals are separated gradually, which are then directly fed to a photo detector. All photo currents are applied to the amplifier which is followed by a Maximum Likelihood Detector (MLD). After passing through the MLD, the signal is detected at the decision circuit by comparing it with a threshold of zero value.

In orthogonal MWSK, the M=2k district symbols are represented by where, $\sigma_0 = \sqrt{P_{th} + P_{shot} + P_{fwm} + P_{s-fwm}}$.

and $P_{s-fwm} = 2(R_d P_{fwm})(R_d P_s)$

$= 2 R_d^2 P_{fwm} P_s$.

$$P_{e1} = 1 - \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \left[1 - Q(y + \sqrt{\frac{2E_s}{\sigma_0}}) \right]^{M-1} e^{(\frac{-y^2}{2})\,dy} \qquad (12)$$

We can write, $\frac{R_d P_s}{\sigma_0} = \sqrt{\frac{2E_s}{\sigma_0}}$

$$P_{e1} = 1 - \frac{1}{\sqrt{2\pi}} \left[\sqrt{2\pi} - \int_{-\infty}^{\infty} e^{-\frac{y^2}{2}} Q(y + \sqrt{\frac{2E_s}{\sigma_0}})\,dy \right]^{M-1} \qquad (13)$$

4.2 Bit Error Rate (BER) of Coded System

Three types of noise also consider in this analysis, thermal noise, shot noise and FWM and all other noise are assume to negligible. The allowable input power is determined for various transmission distances to achieve a BER of 10^{-9} for the bit rate of 10Gbps limiting each system to the same total bandwidth. It is indicating that for a given BER of 10^{-9}, WSK-WDM gives longer repeater spacing.

The probability of bit error rate (BER) for a coded (Convolution Coding) system is given by

$$P_b \le \sum_{h=d_f}^{\infty} W_h P_e(h) . \qquad (14)$$

Where,

$$P_e(h) = \left[\sqrt{2P_e(1-P_e)} \right]^h$$

and

$$P = \Pr obability \;\; of \;\; BER \;\; rate \; for \, ucoded \;\; system.$$

$$= \frac{1}{2} erfc \left[\frac{R_d P_s}{\sigma_n \sqrt{2}} \right]$$

also

$$\sigma = \sqrt{P_{th} + P_{shot} + P_{fwm} + P_{s-fwm}}$$

By taking values for various values of k which is a constant length, like if take k=6 then we are considering the hamming weight from 10 and if take k=7 then we are considering the hamming weight from 12 and so on.

5. RESULTS AND DISCUSSION

Following the analytical approach presented in section 4, we evaluated the BER performance of WSK-DWDM system considering the effect of both binary and M-ary system. For the convenience of the readers the parameters used for computation in this paper are shown in table 1.

Table 1: Nominal Parameters of Optical Communication link

Parameter Name	Value
Bit Rate, B_r	10 Gbps
Temperature	300
Fiber attenuation, α	0.24 dB/Km
Responsivity, R	0.85 A/W
Channel Spacing, D_{ch}	20 GHz
Load Resistance, R_l	50 ohm

In this section, we observe the effect of BER performance for an uncoded system and compare the BER performance for binary and M-ary system with four wave mixing (FWM).

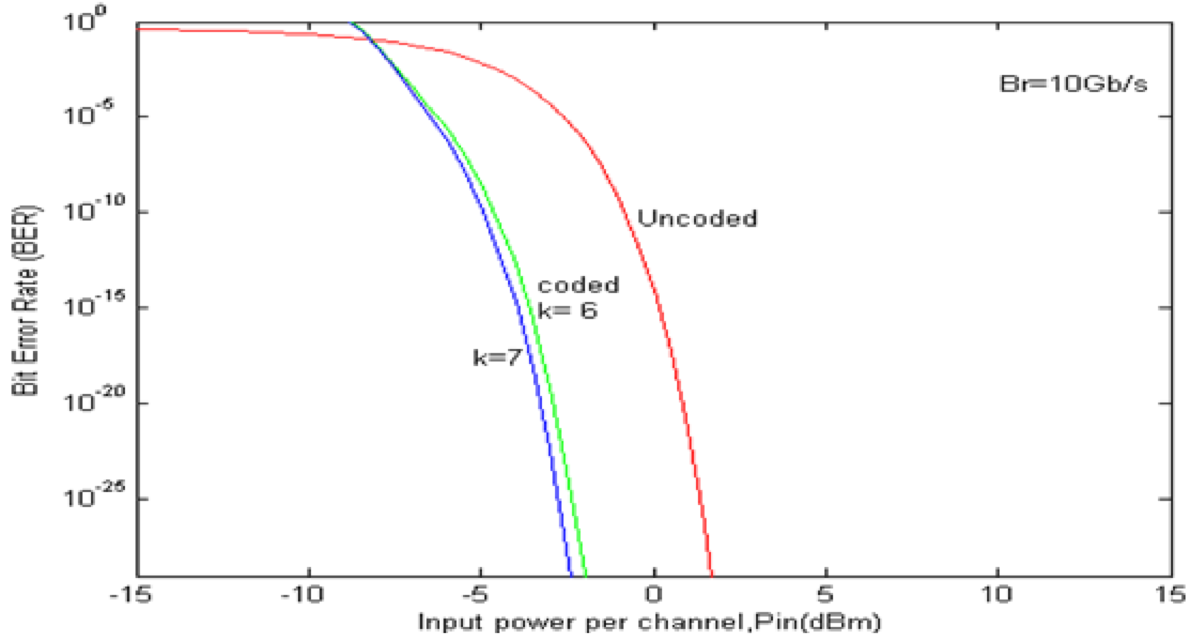

Fig 2: BER vs. Pin (dBm) , coded and uncoded system for WSK-DWDM system. (Br = 10 Gbps)

Fig. 2 shows the plots of BER vs. Pin (dBm) with different constraint length (k). The bit error rate performance results are evaluated at a data rate of 10Gbps per channel. Keeping the others parameters are constant, we compare the performance of the system with and without coding (convolution). It is found that, significant improvement of BER performance is achieved by applying convolution coding. For convolution code of rate ½, the coding gain is 5dB for constraint length k=6 and 6dB for k=7 at an uncoded BER of 10^{-9}.

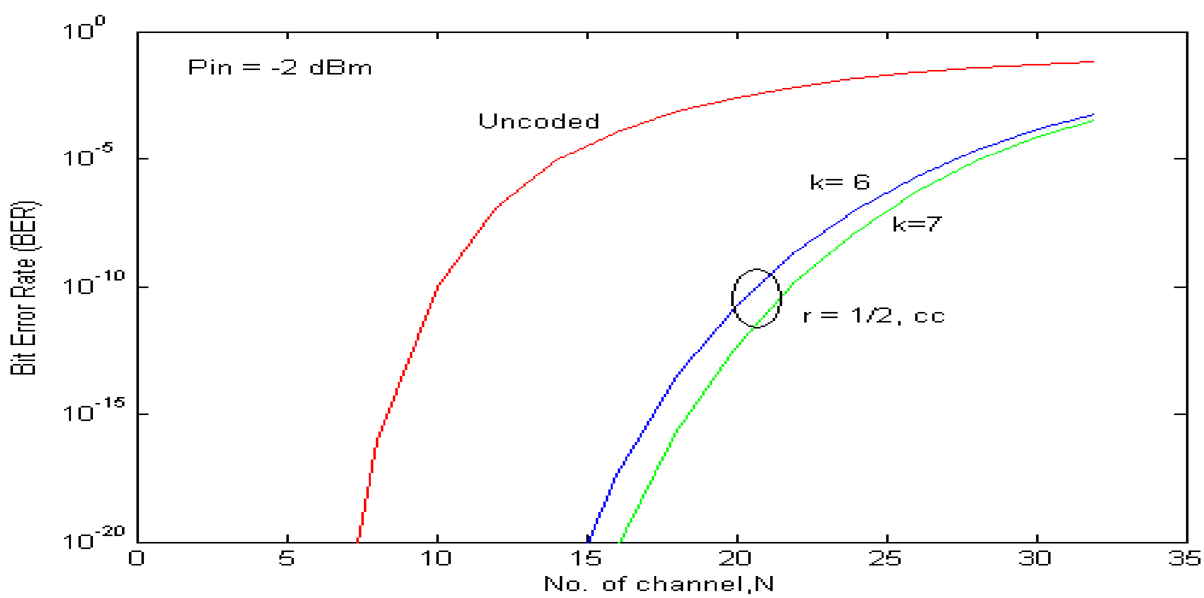

Fig 3: BER vs. No. of channel (N) at constant input power for WSK-DWDM system. (Br=10Gbps, Pin=-2dBm, r=1/2).

Fig 3.shows the plot of BER vs. No. of channel (N) for coded and uncoded system at a constant input power (Pin=-2dBm) and different constraint length (k) at a rate of ½. The plot shows that the remarkable increase in number of channel for coded system than uncoded system. At a BER of 10^{-9} the number of channel used is more pronounced for Pin= -2dBm for coded system than uncoded system.

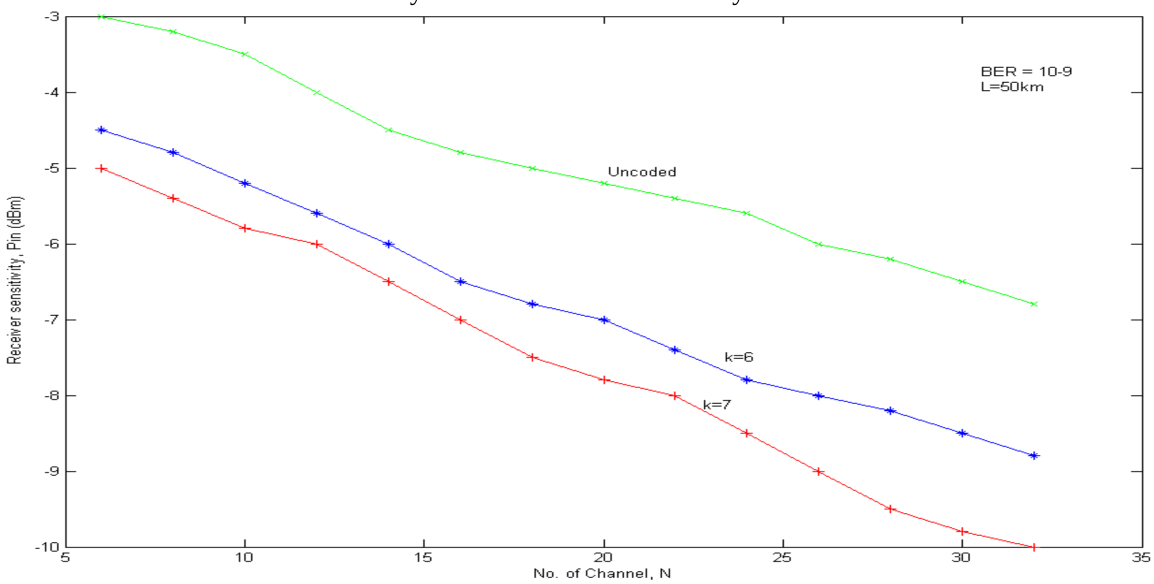

Fig: 4: Receiver sensitivity (Pinmax) vs. No. of channel (N) with and without coding and with four wave mixing for WSK-DWDM system. (Br=10Gbps, BER=10^{-9}, L=50km, Dch=20GHz, r=1/2)

Fig.4 shows the receiver sensitivity vs. no. of channel for coded and uncoded system at constant bit error rate (10^{-9}) and constant fiber length (L=50 km) with four wave mixing (FWM). The plot shows that at a constant channel, more input power is required for uncoded system than a coded system. As a result the receiver sensitivity is improved for the coded system.

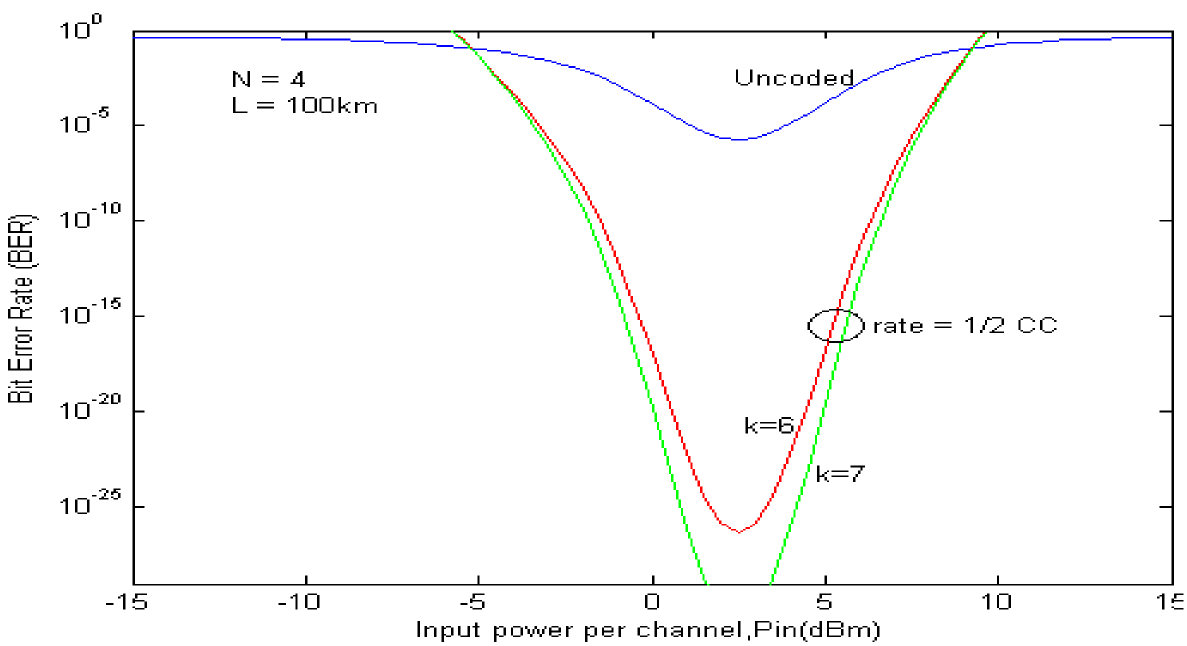

Fig: 5: BER vs. Pin (dBm) for coded and uncoded system with four wave mixing. (N=4, L=100km, Br=10Gbps, r=1/2, Dch=20GHZ)

Fig: 5.Shows the plots of BER vs. Pin (dBm) for uncoded and coded system with four wave mixing. It is noticed that BER performance is much better for coded system than uncoded system up to certain value of input power. After that the BER performance will start to degrade for both the system. For example at 0 dB input power, the BER for uncoded system is about 10^{-3} while for coded (k=6, r=1/2) system the BER is 10^{-11} and for coded (k=7, r=1/2) system the BER is 10^{-15}.

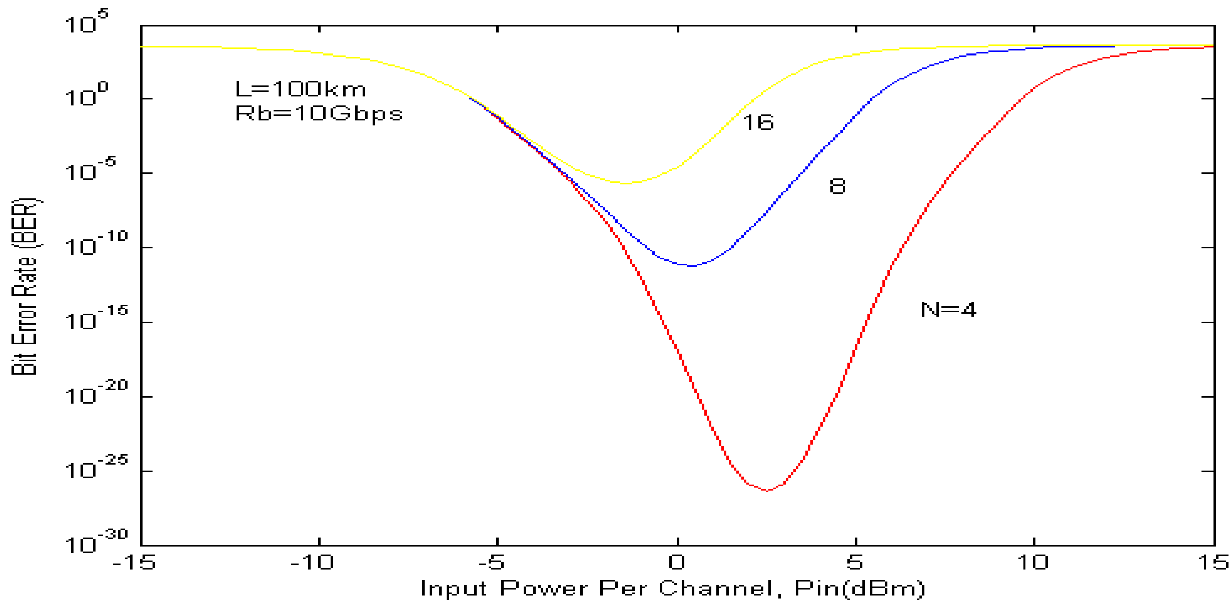

Fig: 6: Bit Error Rate (BER) vs. Input power per channel, Pin(dBm) for different no. of channel for WSK-DWDM. (L=100km, Rb=10Gbps, Dch=20GHz, r=1/2, k=6)

Fig: 6.shows the Bit Error Rate (BER) performance vs. Input power, Pin (dBm) with different no. of channel (N) at constant fiber length (L) and constant bit rate (R_b) with four wave mixing for coded system. It is observed that the bit error rate performance is degrading with increase in channel with constant fiber length. For, example, at 0 dB input power, the BER in the order of 10^{-15}, 10^{-9}, 10^{-6} for N=4, 8 and 16 respectively.

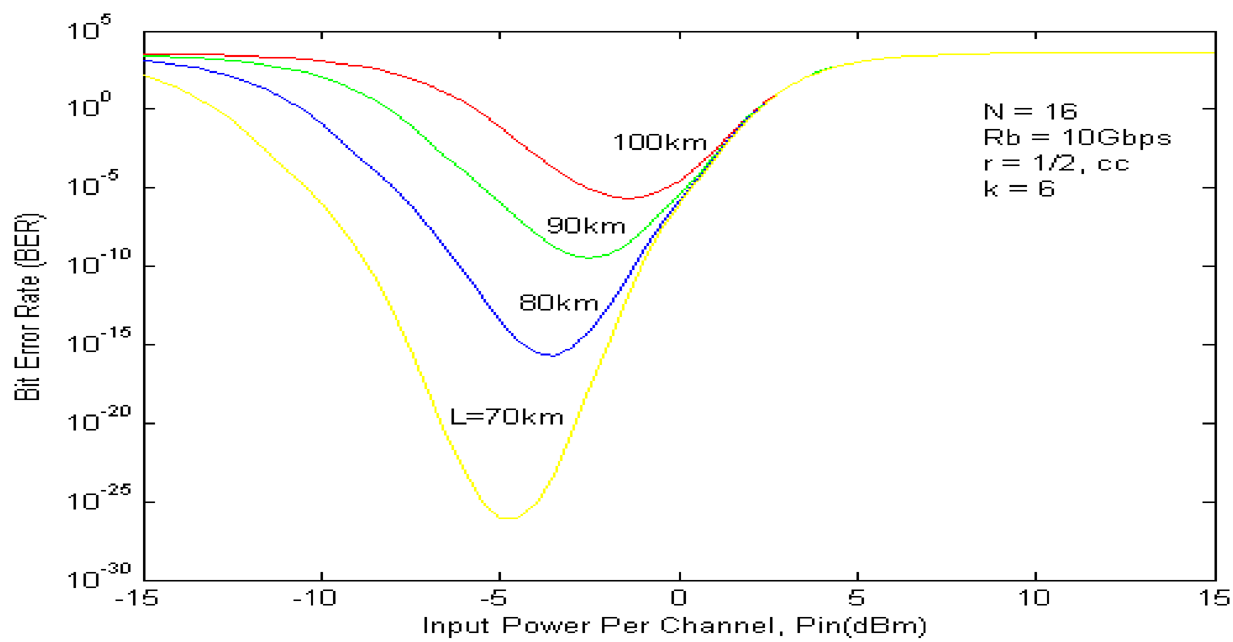

Fig: 7: BER vs. Pin (dBm) for different fiber length for WSK-DWDM with FWM. (N=16, R_b=10Gbps, r=1/2, k=6, Dch=200GHz)

Fig: 7 shows the plots of BER vs. Input power per channel, Pin (dBm) for different fiber length at a constant no. of channel and constant bit rate. It is observed that the system need more power with the increase of fiber length for same amount of BER.

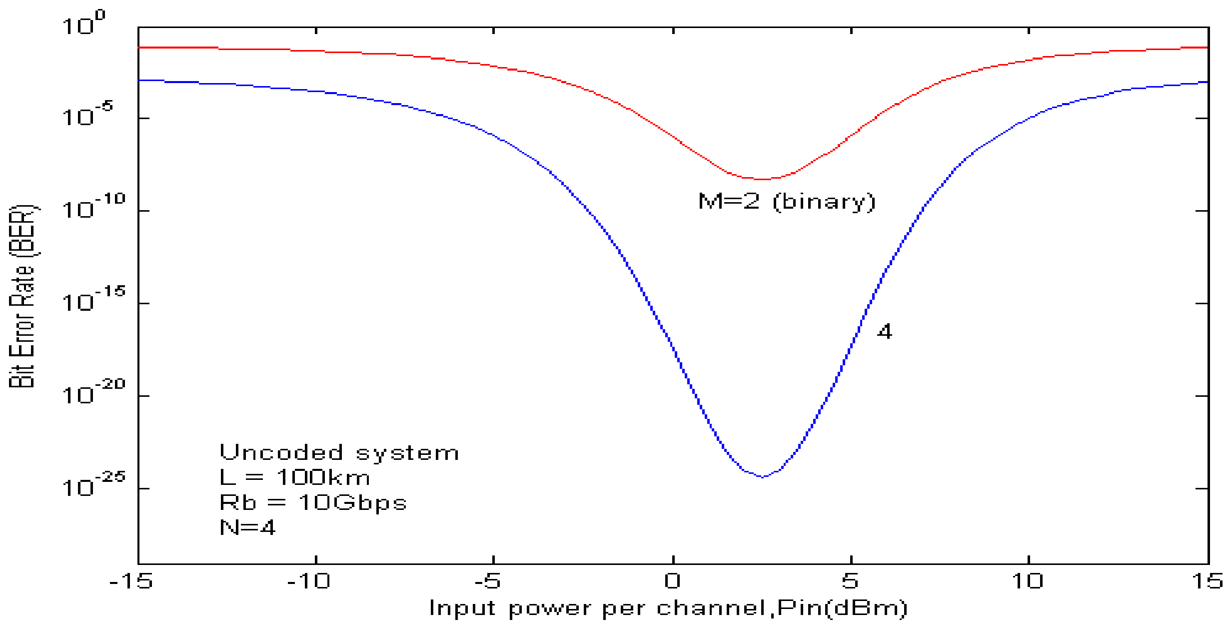

Fig. 8: BER vs. Pin(dBm) for binary and 4-ary uncoded system with FWM. (L=100km, R_b = 10Gbps, N=4, uncoded, Dch=20GHz)

From Fig 8.it is observed that, significant improvement of BER performance is achieved for M-ary system than binary system without coding at constant fiber length, channel and bit rate.

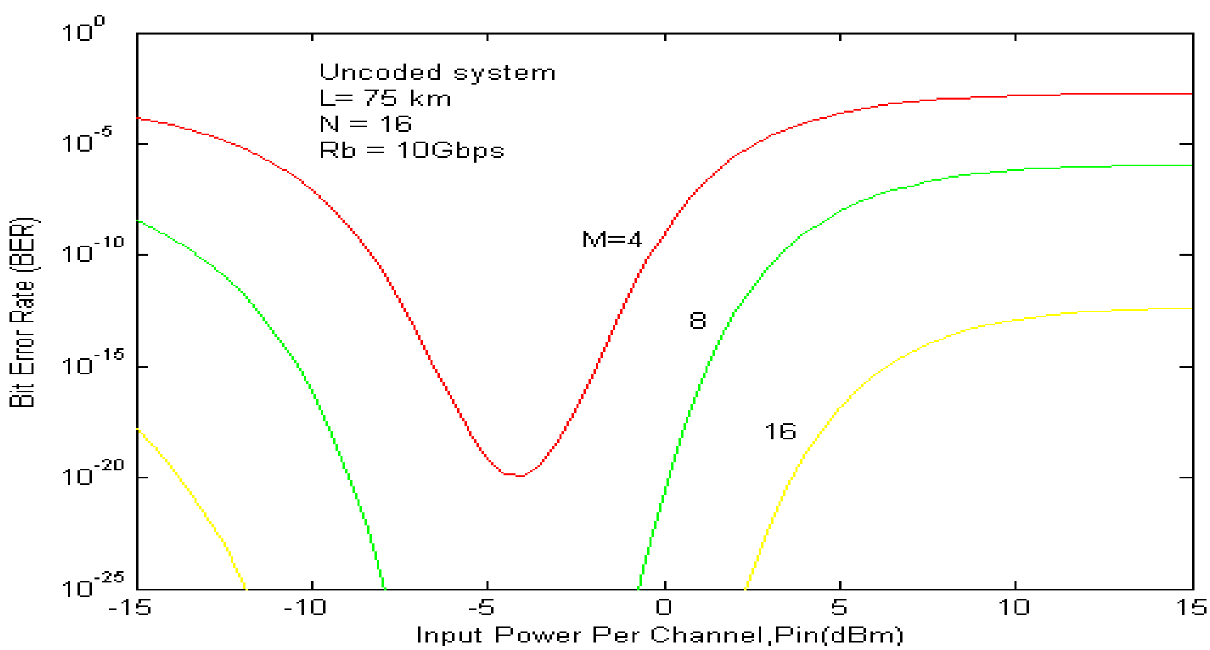

Fig. 9 : BER vs. Input power per channel (Pin) for multiple ary without coding for WSK-WDM. (L=75km, N=16, R_b = 10Gbps, Dch=20GHz, uncoded system)

Fig: 9: shows the BER vs. input power per channel (Pin) with M=4, 8 and 16 at constant fiber length, channel and constant bit rate. We analyze the BER performance with different M value for uncoded system. It is observed that BER performance is more pronounced with increase in no. of ary (M) and results in BER floor. For example, at -15dB input power the BER for binary system is 10^{-2} while for uncoded multiple ary the BER in order of 10^{-4}, 10^{-8} and 10^{-18} for M=4, 8, 16 respectively.

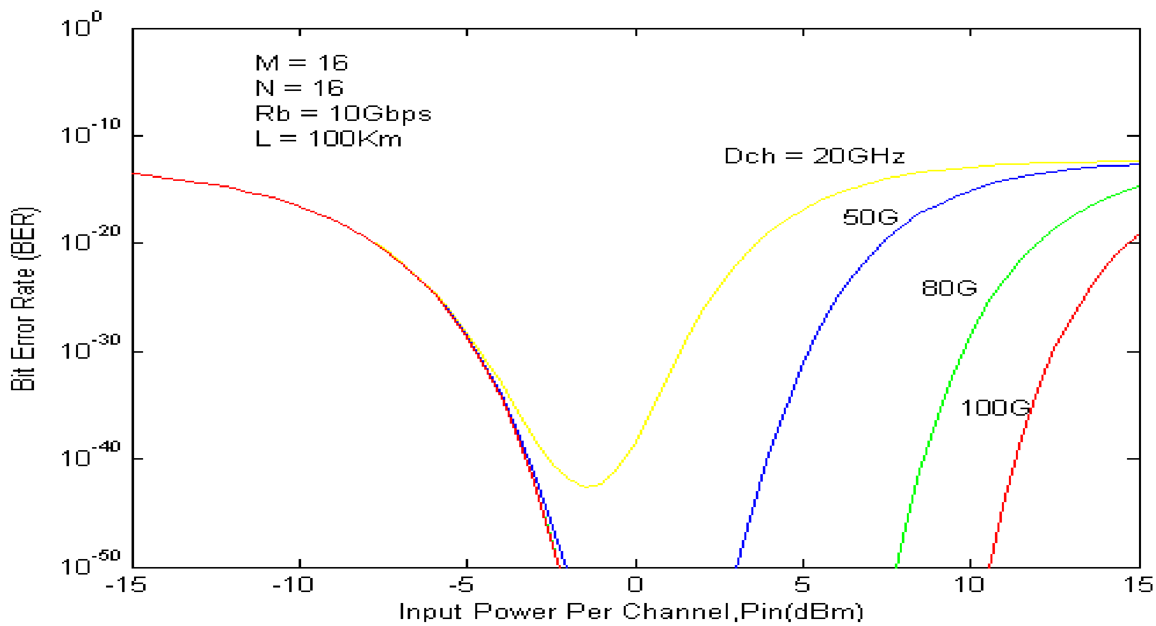

Fig. 10: BER vs. Pin(dBm) for WSK-DWDM system at different channel spacing. (M=16, N=16, L=100km, R_b = 10Gbps, uncoded system)

Fig. 10: BER vs. input power per channel , Pin (dBm) with different channel spacing. It is noticed that the WSK-WDM system suffers almost the same amount of power penalty for lower values of input power at constant BER. But at higher values of input power the amount of power penalty increase with increase in channel spacing.

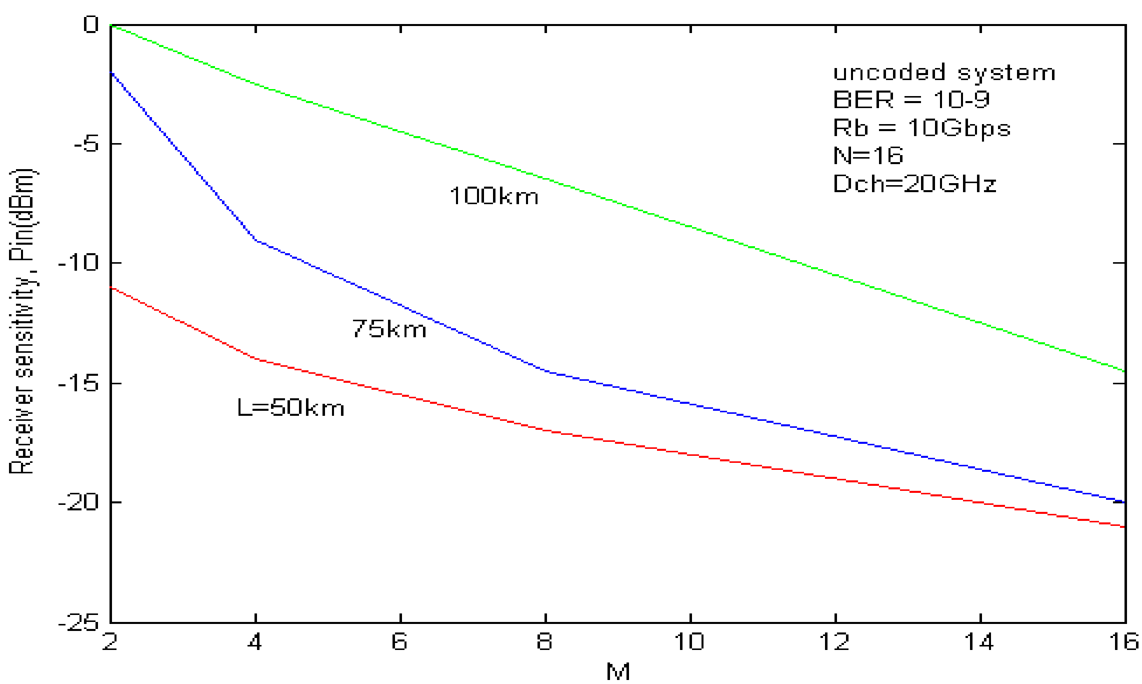

Fig. 11: Receiver sensitivity vs. M for WSK-WDM system at different fiber length. (BER= 10^{-9}, R_b = 10Gbps, N=16, D_{ch} = 20GHz, uncoded system.)

Fig.11. illustrate the receiver sensitivity or power penalty comparison with different fiber length for multiple ary. The plots shows that the amount power penalty with increase in fiber length for a constant ary system. The table 5.3.4. shows the amount of power penalty with different fiber length at 4-ary system. The performance analyze is for uncoded system at constant BER (10^{-9}) with four wave mixing (FWM).

6. CONCLUSION

A detailed analytical approach is presented to evaluate the bit error rate performance of WSK-WDM in presence of FWM. The WSK-WDM system exhibits promising features that will be useful for future high speed, long distance optical networks. FWM becomes the major source of non-linear effects causing interchannel crosstalk and channel power depletion and thereby degrading the system performance. It has been observed that the performance of WSK-WDM system with out coding is not satisfactory; rather the performance is further deteriorated when input power per channel is high. WSK-WDM can provide better performance by applying convolution coding. A remarkable improvement in system performance can be achieved even for uncoded system for M-ary system than binary system. This system offers much better performance: it gives much lower BER, maximum allowable input power per channel is much higher than that of other systems.

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