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Performance Analysis of DWDM System Considering the Effects of Cascaded Optical Amplifiers with Optimum Receiver Gain

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ABSTRACT: *Tremendous growth of rate of traffic due to demands for different multimedia services urges the development of a suitable transmission system capable of handling a large bandwidth. The inherent potential of DWDM like large bandwidth, flexibilities, scopes to upgrade and so many other feature have made it most frequently implied multiplexing technique. In this paper a system has been proposed where an optimum number of amplifiers have been used and an improved APD receiver has been proposed. Theoretical analysis has been carried out to evaluate the performance limitations of DWDM system with intensity modulation direct detection (IM/DD) due to the effects of amplified spontaneous emission (ASE) noise of optical amplifiers and other noises due to an optical receiver. The analysis is presented to find the expression of signal to noise ratio (SNR) and bit error rate (BER) up to the optical receiver taking into account the effect of number of amplifiers and receiver type. Also the system performance has been analyzed by varying amplifier gain, hop length, receiver bandwidth and receiver gain. Result shows that the system performance deteriorates significantly due to power penalty and path penalty.*

Keywords- *Optical Amplifier, BER, Avalanche Photodiode (APD), ASE, IM/DD.*

I. INTRODUCTION

Recently increased bandwidth demand for a large number of growing utilities such as High Definition Television (HDTV), World Wide Web etc. has taken the attention of the recent researchers. Different models have been available for the increased demand without the further extension of the existing facility.

One of the promising techniques to access the huge bandwidth is Wavelength Division multiplexing (WDM). By assigning the incoming signal a specific frequency of light in a limited bandwidth, it increases the bandwidth, flexibility and upgrades the system capacity [1]. Each of the input signals is carried independently, where a dedicated bandwidth for each input signal is allocated. By using WDM, a link capacity on the order of 50 THz can be achieved [2]. An increased number of amplifier affect the Signal to Noise Ratio (SNR) and hence the Bit Error Rate (BER) because of increased amount of spontaneous emission noise. The use of many optical amplifiers in a WDM system after a certain interval makes the signal amplified spontaneous emission beat noise dominate over other noises such as thermal receiver noise and other receiver noises [3]. However, the transmission length increases with the increase in the bit rate and the parameters have the capability of absenting in the network [4]. In Dense Wavelength Division Multiplexing (DWDM), the wavelengths are spaced more closely than that in WDM, which makes it capable of accessing a huge bandwidth. The earlier DWDM systems operated with 4 to 16 wavelengths, while todays DWDM systems support 160 wavelengths transmitting at a speed of 10 Gb/s [5]. A DWDM system has two important features, first the ability to amplify all wavelengths without converting them to electrical system. Second it can carry different type of signals with different speeds simultaneously. The first means that DWDM combines multiple optical signals to amplify them as a group. The second is mainly about the fact that it can carry signals of different types and speeds [6].

Optical amplifier plays an important role by communicating with the other optical amplifiers towards the destination. An optical amplifier regenerate, amplify and control the flow of optical energy from source to destination by reducing the amount of noise. Additionally, in the 1550nm range, it offers a relatively lower insertion loss. Electronic feedback arrangements are also used to control the output power from the amplifier [7]. The most attractive feature of a DWDM system is that the gain region of Erbium Doped Fiber Amplifiers (EDFA) has a gain region located in C band. So the losses due to long span and also the high passive noise are overcome [8].

EDFA is superior in the amplification of the optical signal without any crosstalk penalty even while operating in deep in gain compression. EDFA finds its use in the applications where high output power and high data rate has the major concern. It can reduce a huge amount of data loss and can simultaneously amplify the signal having multi wavelengths. So this type of optical amplifier is used frequently in DWDM systems [9] [10]. In order to achieve a faithful and efficient reception, a handsome amount of optical power should be available at the receiving end. A successful transmission ends with the proper separation of the 0's and 1's from the raw input optical signal [11] [12]. The transmitted signal should have a minimum amount of power that can be sensed by the receiver which is called the sensitivity of the receiver. The receiver sensitivity or the target Bit Error Rate (BER) should be stated otherwise BER is taken as 10^{-12}. The transmitted power should be large enough so that it can maintain a minimum signal power equal to the receiver sensitivity despite the attenuation along the optical fiber. Yet it is not guaranteed that a higher level of transmitted power is surely to maintain the minimum signal power over a long distance at the receiving end. The reason behind this is an increased amount of input signal power gives rise of channel impairment and nonlinearities [13] [14]. The received signal power should lie between the dynamic ranges of the receiver. Otherwise the receiver will be permanently damaged or it will lose the capability to distinguish between 0's and 1's.

In this paper a system model has been proposed where the performance has been analyzed with respect to different parameters and the result has been discussed for better system performance. The paper has been organized as following, section I describes the introduction, section II describes the proposed model, mathematical model is discussed in section III, section IV discusses the result and in section V the conclusion has been drawn.

II. SYSTEM MODEL

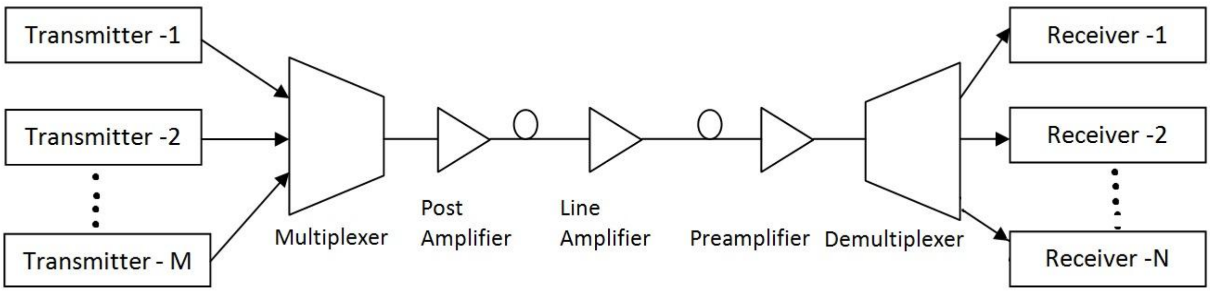

Fig. 1: DWDM system with optical amplifier in cascaded

The proposed model in Fig. 1 shows a simple block diagram of a unidirectional Wavelength Division Multiplexing link having M number of transmitter and N number of receivers. A transmitter consists of laser source, coupling optics and electrons convert electrical signal to optical signal. The multiplexer multiplex the optical signal from different WDM channels. The resultant signal is then sent to optical fiber link. After a certain distance a number of optical amplifiers are used to compensate the loss in fiber. The distance between two successive optical amplifiers is called span length. The typical span length is 60-120 km. There are three different types of optical amplifiers, optical preamplifier, optical power amplifier and linear amplifier. They have different use in different place of the optical link. An optical preamplifier is used in front of a receiver to provide high sensitivity and high gain. After the transmitter the power of the transmitted signal is increased by a power amplifier. An essential feature of a WDM system is add-drop multiplexer (WADM). A WADM separates only one or two channels from a large number of channels while a full demultiplexer separates all the optical channels in a fiber.

III. MATHEMATICAL MODEL

Amplified spontaneous emission is the dominant noise in an optical amplifier. The spontaneous recombination of electrons and holes in the amplifier medium is mainly responsible for this noise. This recombination generates a broad spectral background of photons that gets amplified along with the optical signal. The Power Spectral Density (PSD) of the ASE noise is- [16]

$$N_{sp}(f)= n_{sp}(G-1)hf= Khf \qquad (1)$$

Where,

n_{sp} =Spontaneous emission factor, G=Amplifier gain, h=Plank's constant, f=Frequency of radiation

But despite the ASE noise the optical amplifiers are used in order to compensate the fiber losses. The gain of optical amplifier should be such that it can eliminate the loss along the optical fibers. The total number of optical amplifier will be used solely depends on the span length and the ASE noise. A large span length is preferable to reduce the number of optical amplifier but a large span length reduces the signal strength sufficiently. Receiving a weak signal and amplifying it requires the sensitivity of the optical receiver to be high. So a tradeoff should be made between these limitations.

Let,

P_i= Power output from the Transmitter=Power input to the fiber,

If the amplifier gain is adjusted to compensate for the total losses, then

$$G\,(dB) = P_L\,(dB) = (\alpha fc + \alpha j)\,L\,(dB) \quad (2)$$

Where,

α_{fc}=Fiber cable loss(dB/km), α_j=Joint loss(dB/km),

L=Length of each hop (Distance between two line amplifier in km)

$$G= 10^{-[(\alpha fc + \alpha j)L]/10}, \quad (3)$$

The total number of amplifiers= N = L_t/L, [L_t=Total transmission distance in km]

Then total spontaneous emission noise at the input of the receiver is,

$P_{ase} = NKhfB,$

Where, B =Bandwidth of the receiver,

The optical power received by the receiver, $P_r = P_iG,$

Therefore, the signal to noise ratio at the receiver input

$$\frac{S}{N} = \frac{P_iG}{P_{ase}} = \frac{P_i 10^{-(\alpha_{fc}+\alpha_f)L/10}}{NKhf} \quad (4)$$

Another important fact should be considered while using optical amplifier is Path Penalty Factor (F_{path}). It is the factor by which path average signal energy must be increased (as G increases) in a chain of N cascaded optical amplifiers to maintain a fixed SNR.[15]

Path penalty factor $F_{path}(G) = \frac{1}{G}\left(\frac{G-1}{\ln G}\right)^2$ (5)

The signal to noise ratio is defined as the ratio of signal power to the noise power. For a P-i-N photodiode in an optical fiber communication is given by the following equation-

$$\text{SNR} = \frac{I_p^2}{I_n^2} \quad (6)$$

Where I_p is the photocurrent and I_n is the total noise current. The total noise current is defined as-

$$I_n = \sqrt{i_s^2 + i_t^2}$$

Where i_s is the shot noise current and i_t is thermal noise current. The thermal noise contribution may be reduced by increasing the value of R_L (Load resistance), although this reduction may be limited by bandwidth considerations

$i_s = \sqrt{2e(Ip)B}$, $i_t = \sqrt{4kTB\;/\;R_L}$

Another negligible amount of noise, dark current noise associated with the receiver, $i_d = \sqrt{2e(I_D)B}$

k is the Boltzmann constant (1.38*10^{-23} J/K), B is the photodiode bandwidth, and T(K) is the absolute temperature.
So the overall signal to noise ratio is -

$$\frac{S}{N} = \frac{I_P{}^2}{2eB\,(I_P + I_D) + \frac{4kTBF_n}{R_L}} \qquad (7)$$

Where F_n represents the noise figure, defined by- [15]

$$F_n = \frac{(S/N)_{in}}{(S/N)_{out}}$$

In the Avalanche Photodiode the signal current in the amplifier is increased and the overall SNR is increased as thermal noise remains the same. But the multiplication factor (M) increases the dark current noise and quantum noise which may be a limiting factor. The signal-to-noise ratio for APD receiver can be expressed as- [11]

$$\frac{S}{N} = \frac{I_P{}^2 M^2}{2eB\,(I_P + I_D) M^{2+x} + \frac{4kTBF_n}{R_L}} \qquad (8)$$

Where the factor *x* ranges between 0 and 1.0 and depending on photodiode material.

It is apparent from Eq. (8) that the first term in the denominator increases with increasing *M* whereas the second term decreases. For low *M* the combined thermal and amplifier noise term dominates and the total noise power is virtually unaffected when the signal level is increased, giving an improved SNR. However, when *M* is large, the thermal and amplifier noise term becomes insignificant and the SNR decreases with increasing *M* at the rate of M^x. Therefore, an optimum value of the multiplication factor *M* should be used. [11]

IV. RESULT AND DISCUSSION

From the mathematical model described above the system performance has been analyzed with various parameters. The SNR is determined for different input power, bandwidth, amplifier gain and hop length. Also the system performance has been demonstrated for different types of receivers and their gains. And finally the system performance has been plotted for different receiver gain and bandwidth for the selection of these parameters.

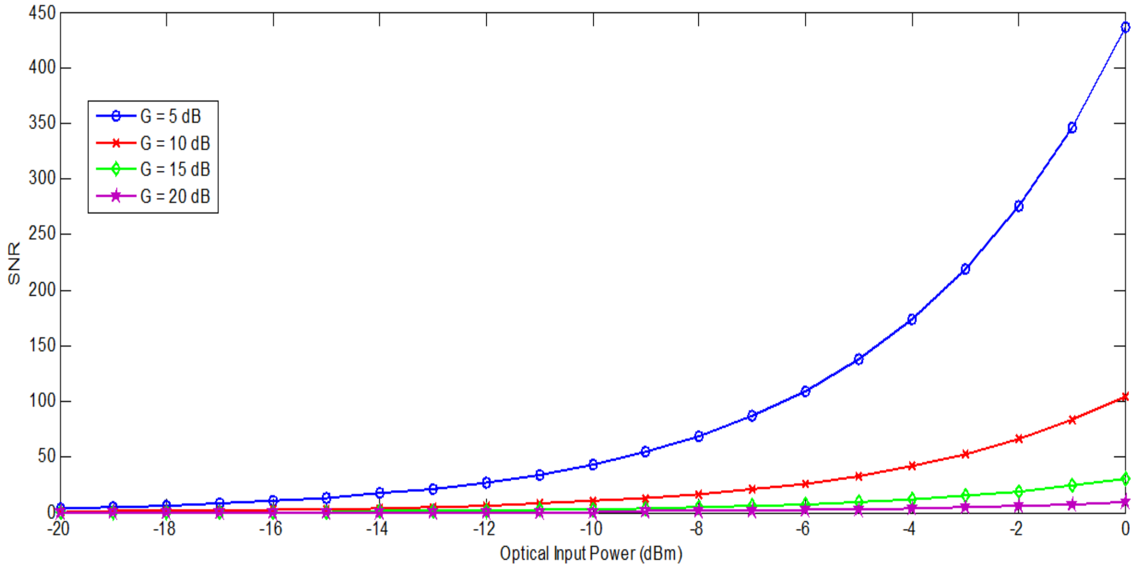

Fig. 2 Amplifier SNR vs input Power for Hop length L=100km, N=10 varying Gain (G=5dB, 10dB, 15dB, 20 dB)

Fig. 2 demonstrate the variation of SNR with the input power to the optical amplifier with a hop length of 100km, no of amplifier 10 and various amplifier gain of 5dB, 10dB, 15 dB and 20 dB. The SNR increases with the increase of optical input power. The SNR is highest for the amplifier gain of 5dB. So the SNR increases with the decrease of amplifier gain.

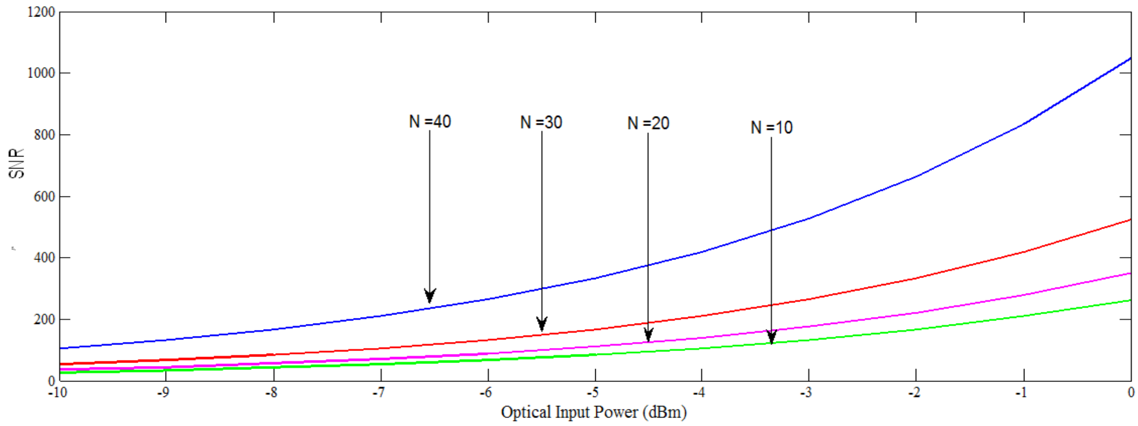

Fig. 3 SNR vs input Power for Hop length L=100km G=10dB varying N=10, 20, 30, 40

In Fig. 3, the SNR has been demonstrated for different amplifier numbers. The SNR has been plotted for the number of amplifiers 10, 20, 30, 40. The output is maximum when the number of amplifiers 40. So it can be concluded that the SNR increases with the increase of number of amplifier.

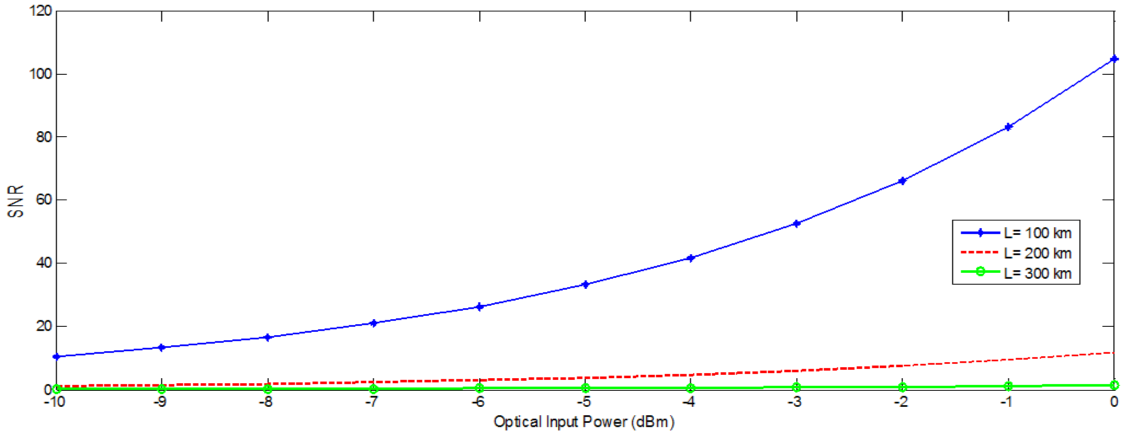

Fig. 4 Amplifier SNR vs Optical Input Power Varying Hop Length L

In Fig. 4, the SNR has been plotted against optical input power with a hop length of 100 km, 200km and 300 km. The SNR is highest for the hop length of 100km. So the SNR increases with the decrease of hop length.

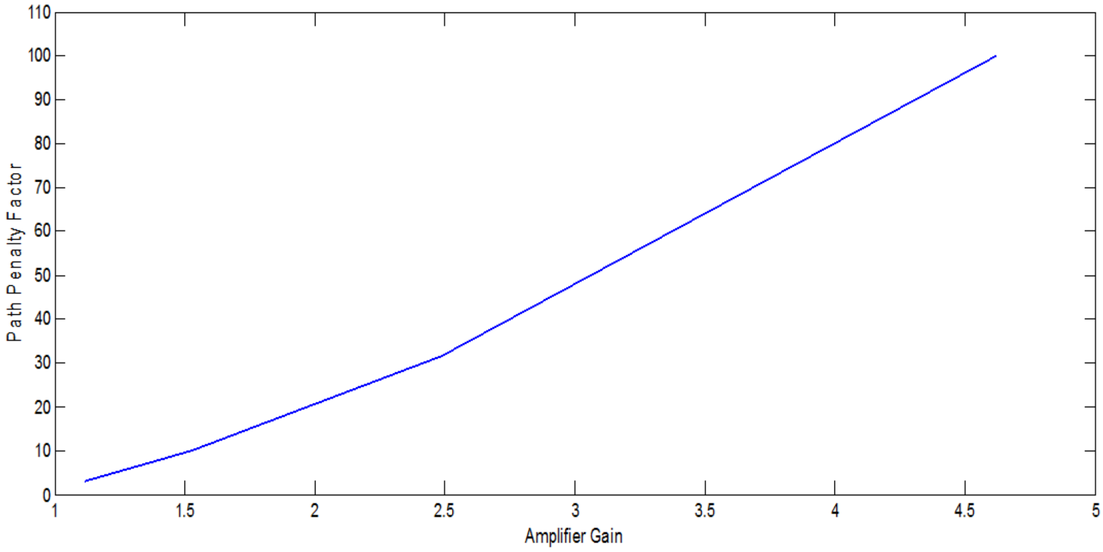

Fig. 5 Path Penalty Factor (F_{path}) vs amplifier gain

Fig. 5 shows the path penalty factor for different amplifier gain. For a higher amplifier gain the path penalty factor increases.

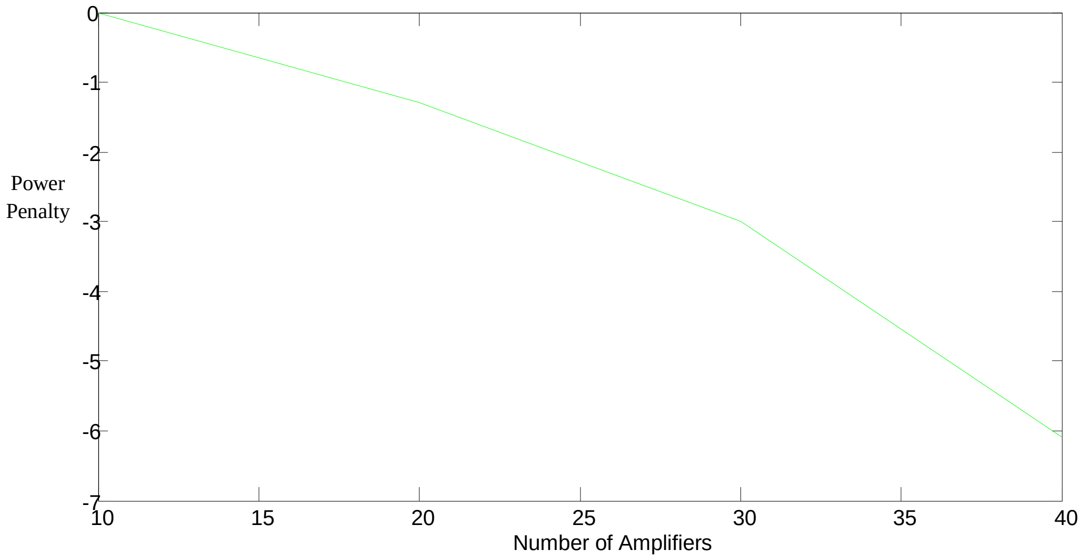

Fig. 6 Power Penalty vs No. of Amplifiers for a fixed SNR=200

In Fig. 6, the power penalty vs no of amplifiers have been demonstrated with a fixed SNR. The power penalty decreases with the increase of number of amplifier.

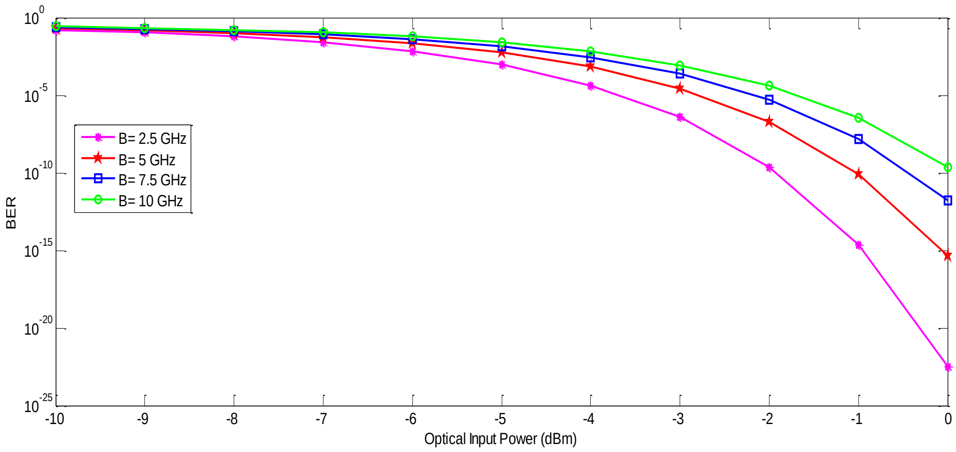

Fig. 7 BER vs Optical Input Power Varying Bandwidth for P-i-N Receiver

In Fig. 7, Bit Error Rate (BER) vs Optical input power has been plotted for different bandwidth. From Eq. (7) and (8) it can be seen that both in a p-i-n photodiode and APD receiver, the noises increase with the increase of bandwidth. Hence the SNR decreases with the increase of bandwidth. When SNR decreases, BER increases. In Fig. 7, the BER is highest when the bandwidth is 10GHz.

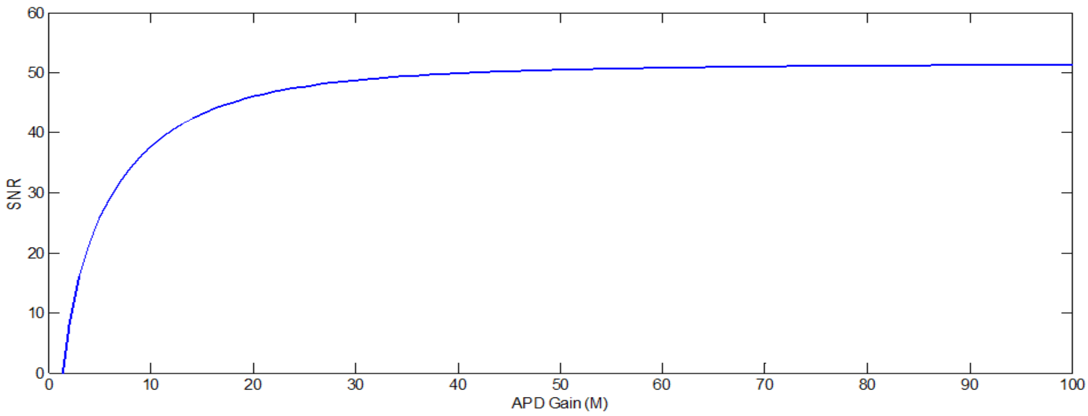

Fig.8 SNR vs APD Gain

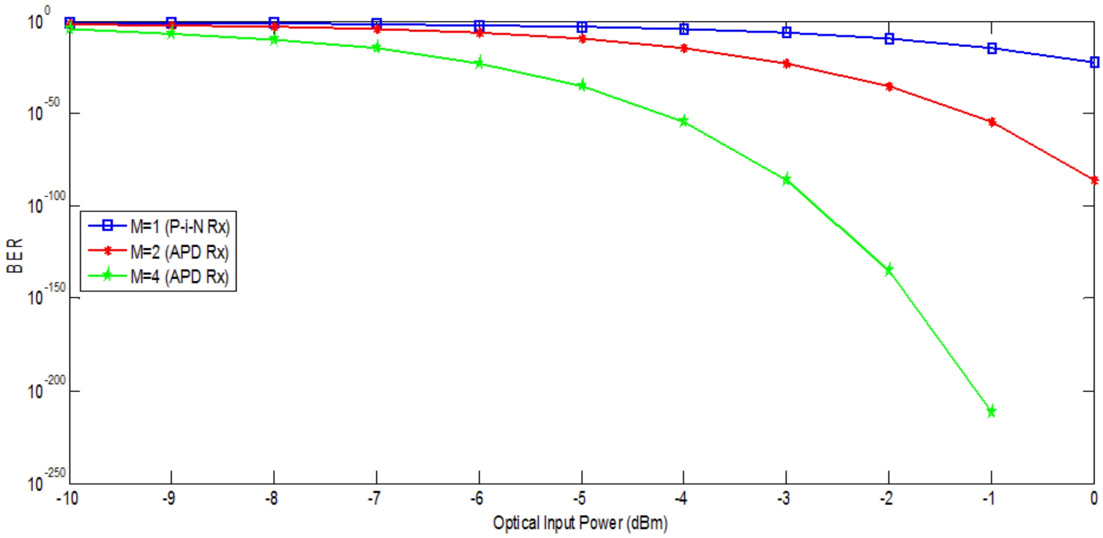

Fig. 9 BER vs Input Power varying APD Gain for a fixed Bandwidth B=5GHz

In Fig 8, the SNR has been plotted against APD gain (M). From M=0 to M=30, the SNR increases rapidly, but after M=30, the increase of the SNR is not significant. In Fig. 9, the BER is plotted vs optical input power for different APD gain. From equation (7) & (8), when the value of M=1, the SNR expression is similar to P-i-N receiver. From Fig. 9, it can be concluded that the BER decreases when the value of M increases. So APD receiver is shows better performance in respect of SNR.

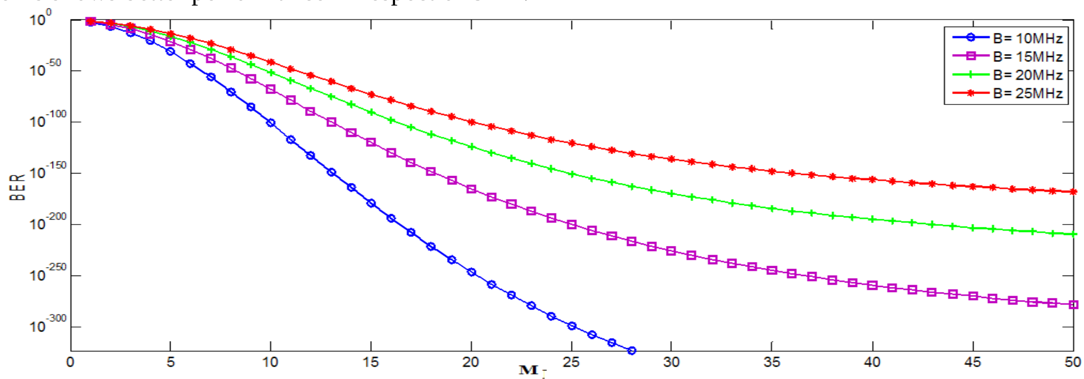

Fig. 10 BER versus APD gain (M) varying bandwidth

In Fig. 10, BER has been plotted against APD gain varying bandwidth. The BER increases when the bandwidth is increased. So combining Fig. 8 and Fig. 10, it can be concluded that for better performance only the value of M should not be limited but also the bandwidth should be limited. Again a small bandwidth corresponds to a smaller receiver size thus minimizes the cost.

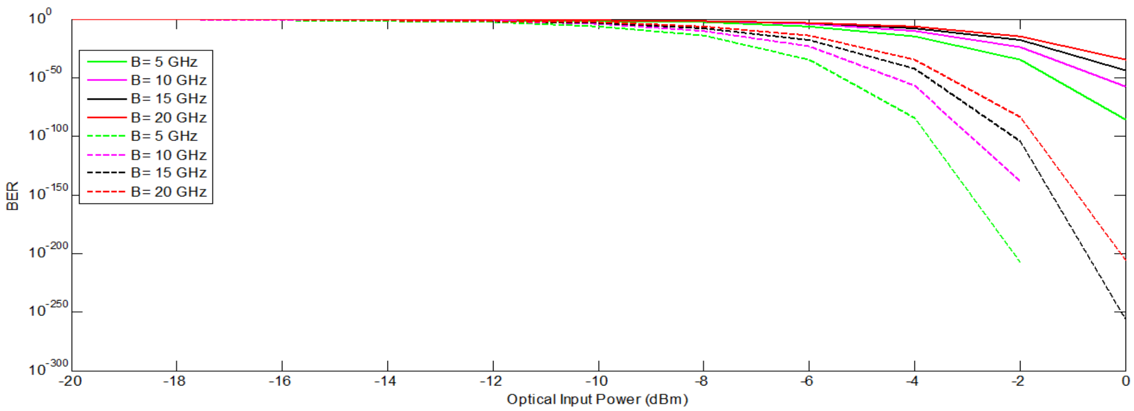

Fig. 11 BER vs Input Power varying Bandwidth for APD Receiver with APD gain M=2 (solid line) and M=5 (dotted line)

In Fig. 11, BER vs input power has been plotted with varying bandwidth and APD gain. The solid line shows the result for M=2 and the dotted line is for M=5. The Figure combines the overall result of analysis of the system. It shows the value of BER is higher for M=2 lower for M=5. Again relatively smaller bandwidth has a lower BER than that of a larger bandwidth.

V. CONCLUSION

A very basic approach to analyze the performance of DWDM systems considering the effect of cascaded optical amplifiers and receiver type has been described. The SNR of optical amplifiers and BER performance has been investigated by varying different parameters. We have also quantified BER performance of DWDM link in terms of receiver bandwidth. It is found that the system has been suffered by power penalty and path penalty and the system performance has also degraded due to higher receiver bandwidth. Both the penalty factor is higher for higher amplifier gain and longer hop length. Therefore, it has been concluded that the system performance can be substantially improved by using marginal amplifier gain and optimum number of amplifiers.

REFERENCES

[1] Gyselings T., Morthier G., and Baets R., "Crosstalk analysis of multiwavelength optical cross connects," *J. Lightwave Technol.*, vol. 17, pp. 1273–1283, Aug. 1999.

[2] Bracket, C., "Dense wavelength division multiplexing networks: principles and applications", *IEEE Journal Select. Areas Commun.*, August 1990, Vol. 8, No. 6, pp. 948-964.

[3] Dods S. D., Anderson T. B., "Calculation of bit-error rates and power penalties due to incoherent crosstalk in optical networks using Taylor series expansions," *J. Lightwave Technol.*, vol. 23, pp. 1828– 1837, April 2005.

[4] Kelvin B. A., Afa J. T., "Bit Error Rate Performance of Cascaded Optical Amplifiers Using Matlab Computation Software," *European Scientific Journal*, vol. 9, No. 3, January 2013.

[5] Bracket, C., "Dense wavelength division multiplexing networks: principles and applications", *IEEE Journal Select. Areas Commun.*, August 1990, Vol. 8, No. 6, pp. 948-964.

[6] Tian, C. and Kinoshita, S., "Analysis and control of transient dynamics of EDFA pumped by 1480- and 980-nm lasers", *IEEE/OSA Journal of Lightwave Technology*, August 2003, vol. 21, No. 8, pp. 1728- 1734.

[7] Reza S. E., Ahsan N., Ferdous S., Dhar R. K., Rahimi M. J., " Analyses on the Effects of Crosstalk in a Dense Wavelength Division Multiplexing (DWDM) System Considering a WDM Based Optical Cross Connect (OXC)" *International Journal of Scientific & Engineering Research*, vol. 4, issue 1, January 2013.

[8] Elrefaie, A., Goldstein, E., Zaidi, S. and Jackman, N., "Fiber-amplifier cascades with gain equalization in multiwavelength unidirectional inter-office ring network," *IEEE Photon. Technol. Lett.*, vol. 5, pp. 1026- 1031, Sept. 1993.

[9] Feuer, M., Kilper, D. and Woodward, S., "ROADMs and their system applications" in "Optical fiber telecommunications V, B: Systems and Networks", ed. Kaminow, I., T. and Willner, A., Academic press editors, EUA, 2008, ch.8.

[10] Senior, J.M. ''*Optical fibre communication principles and practice*'' 3rd edition Prentice Hall 2009.

[11] Connely, M. J., "*Semiconductor optical amplifiers*", Kluwer Academic, 2002.

[12] Ramamurthiu, B., "*Design of Optical WDM Networks,* LAN, MAN, and WAN Architectures:, Kluvier, 2001.

[13] Ramaswami, R. and K. Sivarajan, "*Optical Network: A Practical Perspective"*, 3rd edition, Morgan Kaufmann, 2002.

[14] Keiser, G., "Optical Fiber Comunications", 3rd edition,McGraw-Hill, 2000.

[15] Iqbal, A., Elahee, M., Jahid, A. and Majumder, S.P., "*Performance analysis of WDM system with optical amplifiers in cascade in presence of crosstalk*", Military Institute of Science and Technology (MIST), Dhaka, Bangladesh, 2009,