OPTIMIZING PARAMETERS TO ENHANCE OPTIC SIGNAL-TO-NOISE RATIO IN NATION-WIDE TERRESTRIAL DWDM CASCADED EDFAs FIBER OPTIC COMMUNICATION SYSTEMS

Sung Wook Baik*
Tuan Nguyen Van**
**Sejong University, Seoul, Korea, sbaik@sejong.ac.kr*
***University of Danang, Danang, Vietnam, nvantuan2000@yahoo.com*

ABSTRACT

In this paper, we build algorithm charts to optimize parameters including signal power per channel launched fiber, EDFAs gain for improving optic Signal-to-Noise ratio (OSNR) at optic receiver in Nation-wide terrestrial DWDM cascaded EDFAs Fiber Optic Communication System (FOCS) where the losses due to OADM, GEQ, Connectors at intermediate centers lying on the line were considered. Then, algorithm-based numerical calculating (MathCad propram) is applied in typical system (DWDM Nation-wide FOCS in Vietnam). Optimized results show that the OSNR at the end of transmission line can be increased by (2-5)dB in average comparing with that in cases where parameters are chosen by experience way.

1. INTRODUCTION

In Nation-wide terrestrial DWDM-cascaded EDFAs Fiber Optic Communication Systems, values of signal power launched fiber and EDFAs gain influence directly and considerably on OSNR at the end of transmission line. In practice, the gain of each EDFA is usually chosen to compensate completely the transmission loss of preceded span. Thus, signal power output from an in-line EDFA, i.e., fiber input power, is equal for every span. In that case, each individual equipment and components can operate indifferently well. That operation, however, may be locally optimized, not globally optimized because the interactions and co-ordinations of individual components for the whole line have not been considered yet. This means that system can not be set up their optimized values to achieve a high OSNR at the end of transmission line. OSNR, hence, has not been efficiently used and quality of transferred signal through the system has not been improved.

In this paper, we proposed calculating models of Nation-wide Terrestrial DWDM cascaded EDFAs FOCS where the losses due to OADM, GEQ, Connectors were considered. Then, algorithm charts for calculating FWM noise power, accumulated ASE noise power and for optimizing OSNR at the end of line were built. Numerical calculating was applied in typical system (DWDM Nation-wide FOCS in Vietnam).We found out that after optimizing parameters including signal power per channel launched fiber and EDFAs gain, OSNR can be increased by (2-5)dB in average comparing with that in systems where parameters are chosen conventionally by experience way.

2. CALCULATING MODELS

Typical calculating models of Nation-wide Terrestrial FOCS using DWDM and in-line EDFAs chains are given as in Fig.1.and Fig.2. They are considered as extension of model proposed in [1] by taking into account of ATT including losses of OADM, GEQ, Connectors. Every pair of EDFA-ATT is located at main communication centers in cities lying on the way. When preceded span is longer more than 150km, EDFA-ATT-EDFA configuration is used in order to compensate completely total loss, otherwise EDFA-ATT configuration is proposed. Thus, the M-span system model considered here consists of N amplifiers depended on number of these different configurations. For example, N=M-1 in fig.1 and N=M in fig.2. ATT_1, ATT_2, ..ATT_{M-1} losses due to OADM, Gain Equalizer (GEQ), Connectors…

1-4244-0569-6/06/$20.00 ©2006 IEEE

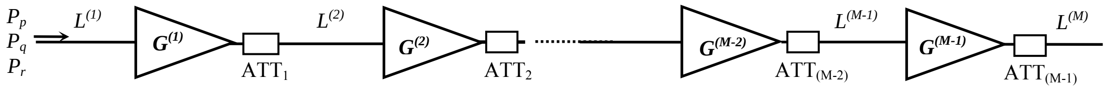

Fig.1. General Model of Nation-wide Terrestrial DWDM Cascaded EDFAs System using one-stage amplifier configuration

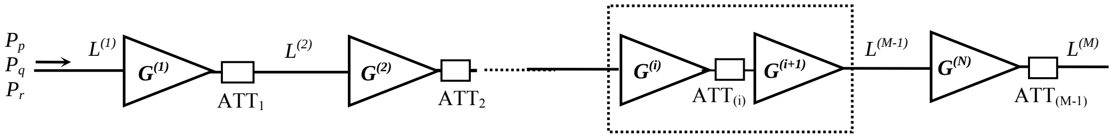

Fig.2. General model of Nation-wide Terrestrial DWDM Cascaded EDFAs System using one and two-stage amplifier configurations

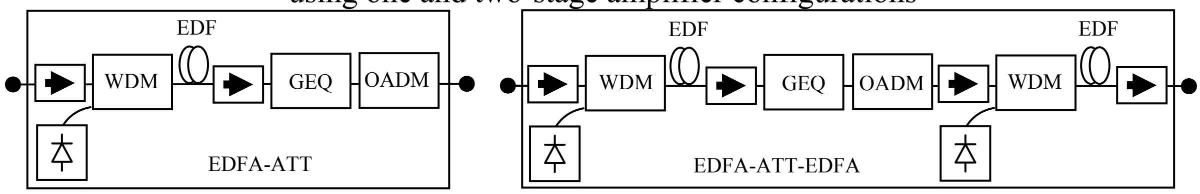

Fig.3. One-stage (EDFA-ATT) and two-stage amplifier (EDFA-ATT-EDFA) configurations

+ Optical Signal-to-Noise Ratio (OSNR) at the end of transmission line

In this paper, total optical power launched fiber is limited less than 20dBm and bit-rate of each channel is 2.5Gb/s. Thus, the other effects of fiber nonlinearities (SPM, XPM, SBS, SRS) are significantly less than FWM one and can be neglected[1]-[4]. As a result, OSNR at the end of line for mth channel (f_m) is shown as:

$$OSNR(f_m) = \frac{P_{sig}(f_m)}{P_{FWMtot}(f_m) + P_{ASEtot}(f_m)} \quad (1)$$

+ Signal power at the end of line

$$P_{sig}(f_m) = \exp\left[\sum_{i=1}^{M}(-2A^{(i)})\right] \times \exp\left[\sum_{i=1}^{M-1}(-ATT^{(i)})\right] \prod_{i=1}^{N} G^{(i)} P_{in/ch} \quad (2)$$

+ FWM noise at the end of line

The expression of FWM noise power[1], P_{pqr}, at the end of transmission line is extended by taking into account of ATT including losses of OADM, GEQ, Connectors, and is shown as (in c.g.s, units).

$$P_{pqr} = \frac{1024\pi^6}{n_0^4\lambda^2c^2}(d\chi)^2\frac{P_pP_qP_r}{A_{eff}^2}\exp\left[\sum_{m=1}^{M}\left(-2A^{(m)}\right)\right]\times \exp\left[\sum_{m=1}^{M-1}\left(-ATT^{(m)}\right)\right]\times\left|\sum_{m=1}^{N}\left[\prod_{k=1}^{m-1}\left(\sqrt{G_p^{(k)}G_q^{(k)}G_r^{(k)}}\right)\times \exp\left[\sum_{k=1}^{m-1}\left(-2A^{(k)}+i\Delta\psi^{(k)}\right)\right]\times\prod_{k=m}^{N}\left(\sqrt{G_F^{(k)}}\right)\times \left(\frac{1-\exp\left[\left(-\alpha_1+i\Delta\beta_1\right)L_1^{(m)}\right]}{\alpha_1-i\Delta\beta_1}+\exp\left[\left(-\alpha_1+i\Delta\beta_1\right)L_1^{(m)}\right]\times \frac{1-\exp\left[\left(-\alpha_2+i\Delta\beta_2\right)L_2^{(m)}\right]}{\alpha_2-i\Delta\beta_2}\right)\right]\right|^2 \quad (3)$$

As system has a large number of channels, at a certain frequency f_m, a significant amount of FWM waves is created by various combinations of channels in system[1],[5],[6],[7]. As a result, the FWM power $P_{FWMtot}(f_m)$ at f_m is given as:

$$P_{FWMtot}(f_m) = \sum_{f_r = f_p + f_q - f_m}\ \sum_{f_q}\ \sum_{f_p} P_{pqr} \quad (4)$$

+ Accumulated ASE noise at the end of transmission line

$$P_{ASEtot}(f_m) = exp\{-2A(M)\}\times \left[\left(\sum_{i=1}^{N-1}P_{ASEi}(f_m)\prod_{j=i}^{N-1}exp\{-2A(j+1)G_{j+1}\}\right) + P_{ASE(N)}(f_m)\right] \quad (5)$$

3. ALGORITHM CHARTS

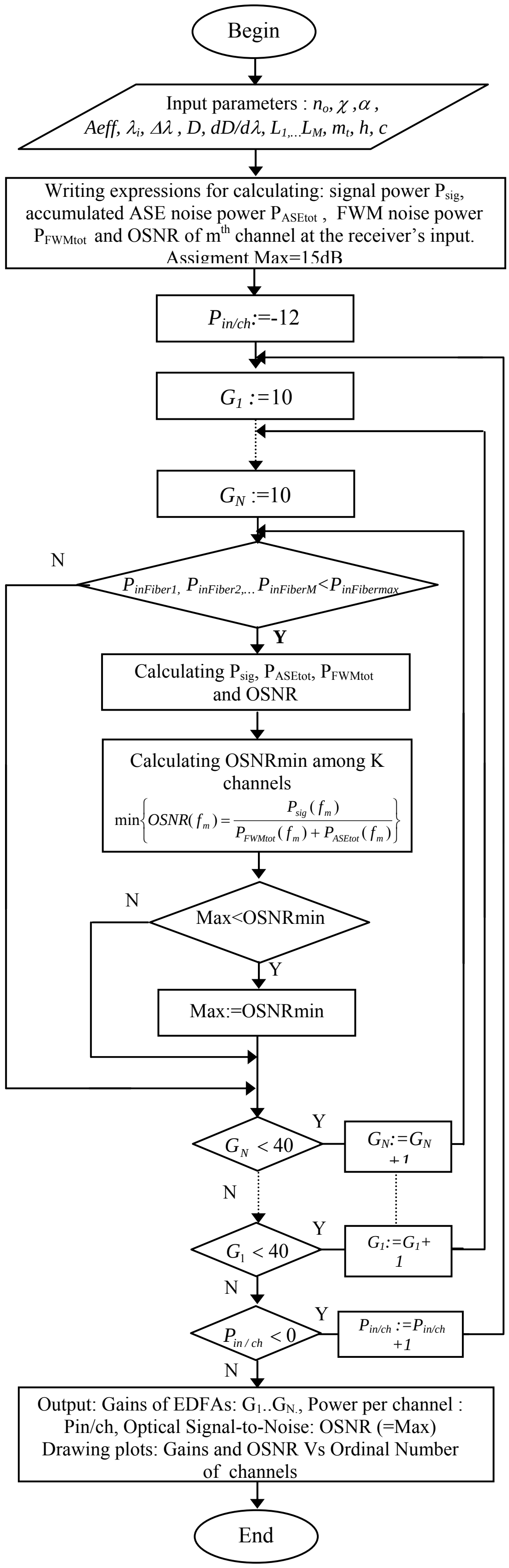

Fig.4. Main algorithm chart for optimizing OSNR at the end of Line

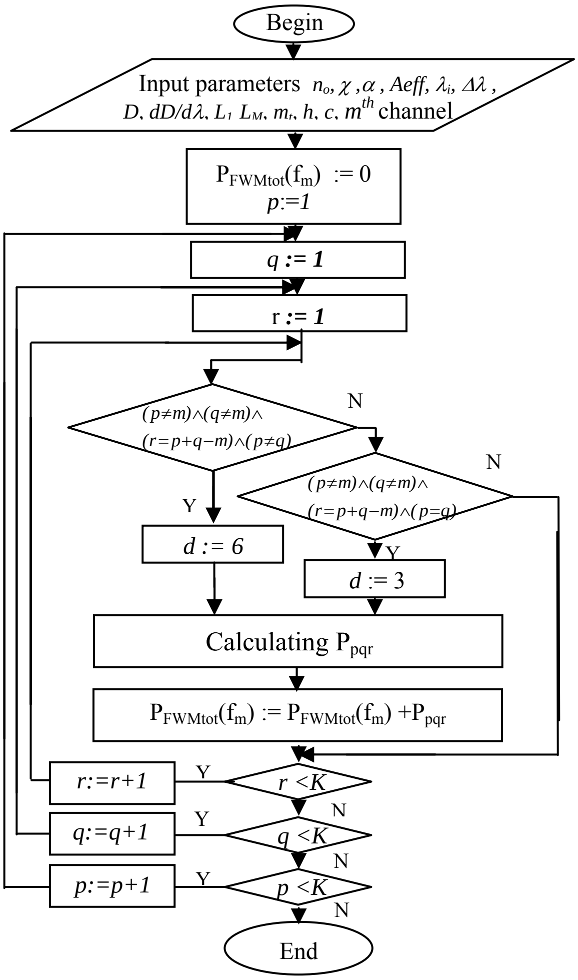

Fig.5. Algorithm chart for calculating FWM noise power $P_{FWMtot}(f_m)$

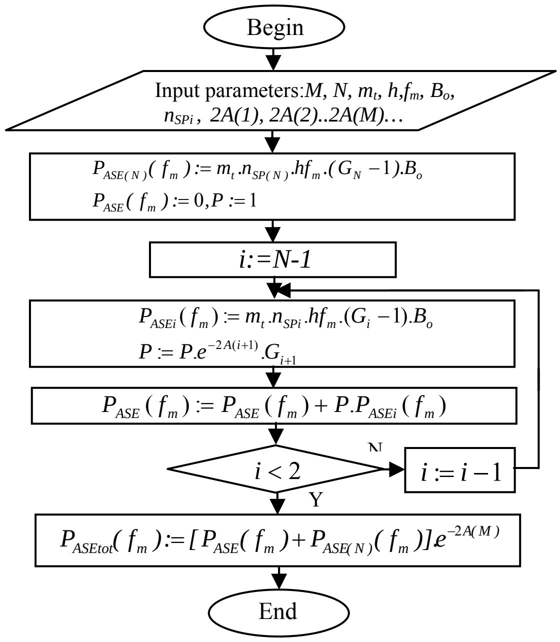

Fig.6. Algorithm chart for calculating Accumulated ASE noise power $P_{ASEtot}(f_m)$

4. APPLICATION

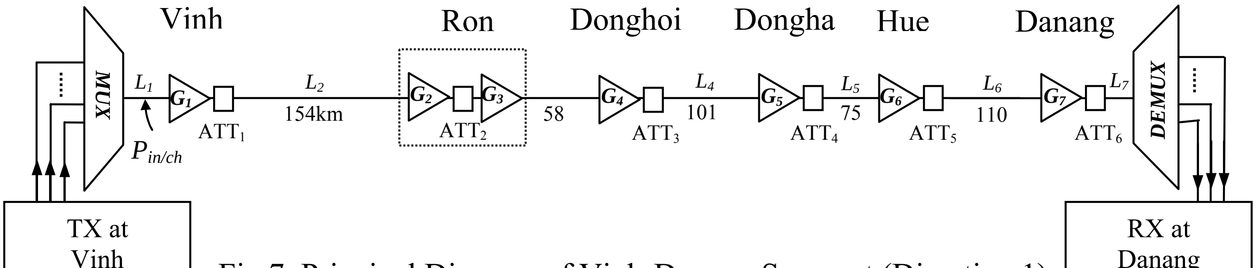

Fig.7. Principal Diagram of Vinh-Danang Segment (Direction 1)

In order to illustrate the optimizing parameters in one concrete Nation-wide system where every span length between EDFAs is different, Vietnam Nation-wide DWDM Optical Communication System is chosen as a typical one. It consists of 5 main segments[10] connected from Hanoi (capital) to Ho Chi Minh City through many cities located on the way. In each segment, EDFAs are established at communication center in the cities lying along the line. Therefore, span length between every two EDFAs is different. Communication is transferred in two directions. In this system, Hanoi, Vinh, Danang, Quynhon, Phanrang and Ho chi Minh city play the role of both segment beginning and end positions where terminal DWDM equipments including optical transmitting and receiving cards are set up. Making algorithm and calculating optimal parameters, thus, can be carried out independently in five segments for achieving maximum of OSNR at the end of them. We consider Vinh-Danang transmission line as one of the typical segments for applying algorithm charts mentioned in section 3. It connects 6 cities including Vinh-Ron-Donghoi-Dongha-Hue-Danang, shown as fig.7. Other segments in this system will be calculated and optimized similarly.

5. NUMERICAL RESULTS AND ANALYSIS

In this segment, two-stage amplifier configuration consisting of EDFA-ATT-EDFA is used at Ron Center because its preceded span (L_2=154km) is longer more than 150km. In other centers, one-stage amplifier configurations, EDFA-ATT are proposed due to preceded span is less than 150km. The number of spans, EDFAs and ATTs are 7, 7 and 6, respectively.

We assume that $P_{in}^{(1)}= P_{in}^{(2)}=.. P_{in}^{(K)}=P_{in/ch}$ and $G_p^{(k)}=G_q^{(k)}=G_r^{(k)}=G^{(k)}$ because Gain Equalizers were located in every ATT. $n_{SP1}= n_{SP2}..= n_{SP7}$=1.4, m_t=2. Channel spacing is equal 0.8nm.

$P_{in/ch}$: (-12dBm ÷ 0dBm); G_1, G_2 … G_7 : (10dB ÷ 40dB). Alcatel ColorLock single mode fiber chosen [7],[8], α=0.21dB/km, D=18ps/(nm.km), $\frac{dD}{d\lambda}$=0.09ps/(nm^2.km), A_{eff}=80.10^{-12}m^2. ATT is equal 6dB including OADM, GEQ, Connectors losses[9].

First, 16-channel transmission line is examined. As mentioned in section 1, in practice system, gain of EDFAs are determined as follows G_1=10, G_2=30, G_3=14, G_4=12, G_5=27, G_6=22, G_7=29dB. Algorithm charts in fig.5, and fig.6 basing on expressions (3), (4), (5) are used for calculating FWM (P_{FWMtot}) and ASE (P_{ASEtot}) noise powers, respectively.

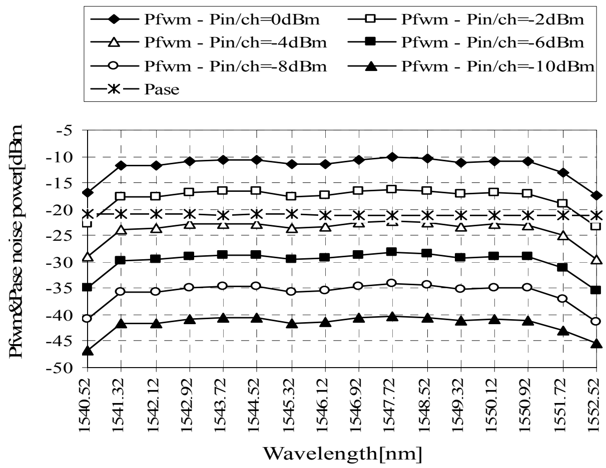

Fig.8. P_{FWMtot} and P_{ASEtot} [dBm] versus wavelength for different values of $P_{in/ch}$ in 16-channel Transmission Line.

Results in fig.8 and fig.9 show that P_{FWMtot} and P_{ASEtot} noise powers at the end of segment change versus wavelength for different values of $P_{in/ch}$.

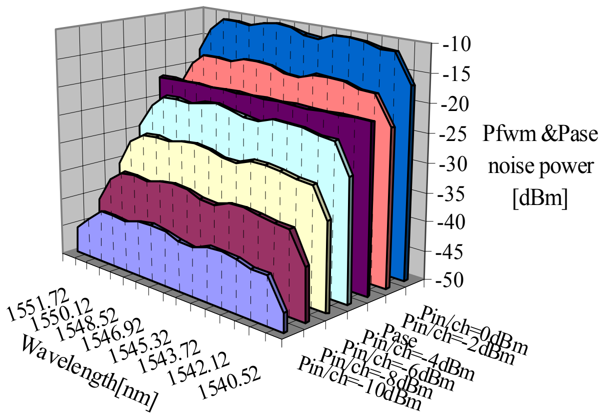

Fig.9. P_{FWMtot} , P_{ASEtot} versus wavelength for different values of $P_{in/ch}$ in 16-channel Line (3-Dimension Graph)

Fig.10 presents variation of OSNR versus wavelength for different $P_{in/ch}$.

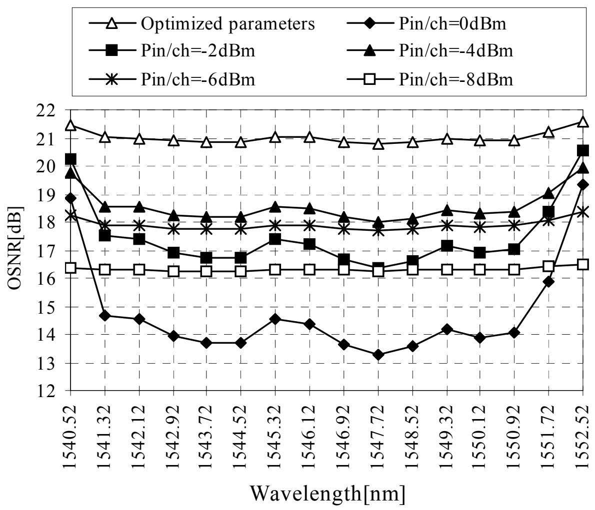

Fig.10. OSNR [dB] versus wavelength for different $P_{in/ch}$ in 16-channel Line

The optimized results are found as follows, $P_{in/ch}$ =-4dBm, G_1=12, G_2=29, G_3=13, G_4=11, G_5=26, G_6=21, G_7=28dB. OSNR can be improved by (2dB÷5dB) in average thanks to optimizing parameters comparing with that in the cases where parameters are chosen conventionally (following experience way). Fig.11. shows Gain of EDFAs in cases of optimized and not-optimized parameters in Vinh-Danang Transmission Line.

In fig.12, OSNR values are shown as a function of wavelength with different values of PinFibertot. When G_1 increases from 12dB to 15dBm, corresponding to rising of PinFibertot from 16dBm to 19dBm, OSNR at the end of line decreases because both P_{ASEtot} and P_{FWMtot} increase.

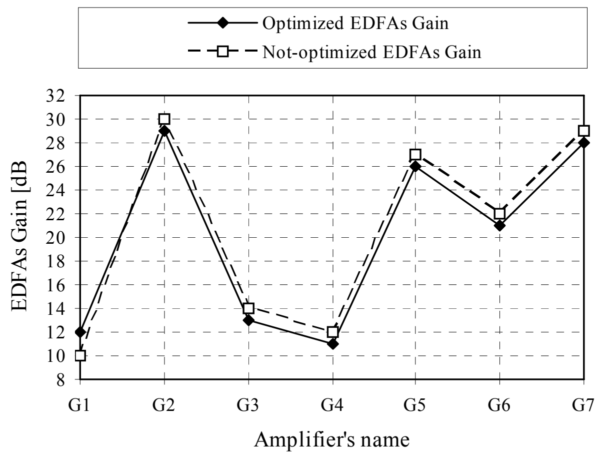

Fig.11. Gain of EDFAs in cases of optimzed and not-optimized parameters

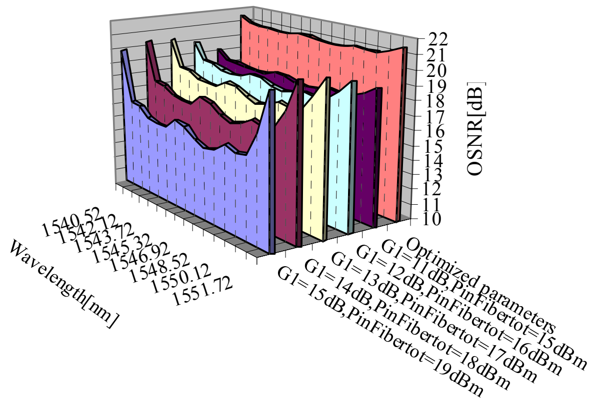

Fig. 12. OSNR [dB] versus wavelength for different PinFibertots in 16-channel Line

We then investigate similarly cases of 24-channel and 32-channel transmission lines. Results are presented in fig.13 and fig.14, respectively. We found out that the shapes of OSNRs in these two cases are also similar to that in 16-channel one. OSNR improving (2-5)dB in average comparing with conventional choosing can be also achieved when parameters in system are optimized. They are determined as follows $P_{in/ch}$ = -4dBm, G_1=12, G_2=29, G_3=13, G_4=11, G_5=26, G_6=21, G_7=28dB.

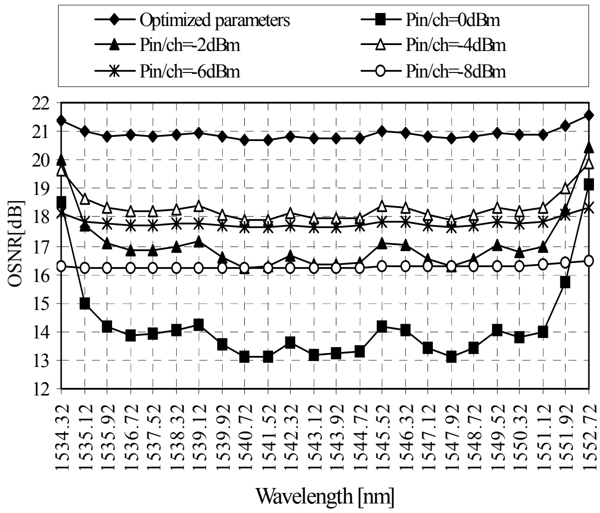

Fig.13. OSNR [dB] versus wavelength for different $P_{in/ch}$ in 24-channel Line

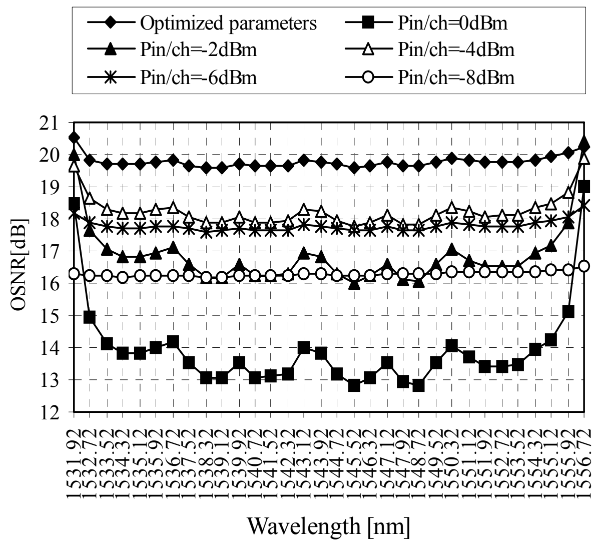

Fig.14. OSNR [dB] versus wavelength for different $P_{in/ch}$ in 32-channel Line

6. CONCLUSION

In this paper, typical calculating models of Nation-wide Terrestrial DWDM cascaded EDFAs FOCS were considered as extension of model proposed in [1] by taking into account of ATT including losses of OADM, GEQ, Connectors. Algorithm charts, then, were built to determine optimized parameters, including signal power per channel launched fiber and gain of all EDFAs for improving optic Signal-to-Noise ratio at optical receiver. Algorithm-based numerical calculating, then, was applied in typical system (DWDM national FOCS in Vietnam). Optimized calculated results showed that OSNR could be improved by ($2dB \div 5dB$) in average comparing with that in the cases where parameters were chosen conventionally by experience way. It means that we can enhance quality of the transferred signal through whole the system thanks to optimizing system parameters.

REFERENCES

[1]. W. Zeiler, F. D. Pasquale, P. Bayel, Member, IEEE, J.Midwinter, Fellow. IEEE, "Modeling of four-wave mixing and gain peaking in amplified WDM optical communication systems and networks", Journal of Lightwave Technology, Vol. 14, No. 9, pp. 1933-1942, September 1996.

[2]. A. R. Chraplyvy, "Limitations in lightwave communications imposed by optical-fiber nonlinearities", Journal of Lightwave Technology, Vol. 13, pp.1548-1557, Oct. 1990.

[3]. A. Naka and S. Shigeru, "Transmission distance of in-line amplifiers systems with group-velocity-dispersion compensation", Journal of Lightwave Technology, Vol. 13, pp.862-867, May 1995.

[4]. D. Marcuse, A. R. Chraplyvy, and R. W. Tkach, "Dependence of cross-phase modulation on channel number in fiber WDM systems," Journal of Lightwave Technology, Vol. 13, pp.885-890, May 1995.

[5]. K. Inoue and H. Toba, "Fiber four-wave mixing in multi-amplifier systems with nonuniform chromatic dispersion," Journal of Lightwave Technology, Vol. 13, pp. 88-93, Jan. 1995.

[6]. Y R Zhou, A Lord, E S R Sikora "Ultra-long-haul WDM transmission systems", BT Technology journal, Vol. 20, No. 4, October 2002.

[7]. Govind P. Agrawal, "Fiber-Optic Communication Systems", John Wiley & Sons, Inc., New York, third Edition, 2002.

[8]. http://www.optics.rochester.edu/users/gpa/ /opt428b.pdf

[9]. Emmanuel Desurvire, Dominique Bayart, Bertrand Desthieux, Sebastien bigo,"Erbium-Doped Fiber Amplifier, Device and System Developments", Wiley, New York, 2002.

[10]. Nortel Networks Optera Long Haul 1600G, December 2002, Danang telecommunication station, Vietnam National Telecommunication 3, 5-2004.