Journal Media and Communication Studies Vol. 1(4) pp. 056-072, 0ctober, 2009
Available online http://www.academicjournals.org/jmcs

Full Length Research Paper

Ultra wide band (UWB) of optical fiber Raman amplifiers in advanced optical communication networks

Abd El–Naser A. Mohammed and Ahmed Nabih Zaki Rashed*

Electronics and Electrical Communication Engineering Department, Faculty of Electronic Engineering, Menouf 32951, Menoufia University, Egypt.

Accepted 7 September, 2009

In the present paper, we have analyzed numerically the ultra wide band (UWB) optical fiber Raman amplifiers in advanced optical communication networks. Moreover, we have developed the numerical transmission and propagation techniques based on mathematical laboratory programming to solve the coupled optical wave equations to obtain design parameters, operational characteristics, and its implementation in the light wave modulated envelop propagation equations for transmission of multi Gbit/sec signals in dense wavelength division multiplexing optical communication systems. We have investigated numerically and parametrically the soliton transmission technique to handle the bit rates and products either per link or per channel in all pumping direction configurations to upgrade optical network efficiency in order to support ultra high capacity of number of users. Also, we have concentrated on the fiber Raman optical amplifier is quickly emerging as an important part of ultra long-distance, high-capacity, and high-speed optical communication systems.

Key words: Raman amplification technique, advanced optical networks, ultra wide-band, dense wavelength division multiplexing (DWDM), space division multiplexing (SDM).

INTRODUCTION

Optical fiber Raman amplifiers are attractive for DWDM transmission systems due to their advantages of broad amplification bandwidth and flexible central wavelength (Islam, 2002). With recent developments of optical pump sources with high power near 1.4 µm wavelength and highly nonlinear fiber (HNLF) having a peak effective Raman gain coefficient more than ten times that of conventional single-mode fiber, discrete optical fiber Raman amplifiers are emerging as a practical optical amplifier technology, especially for opening new wavelength windows such as the short (S) and ultra-long and (U) wavelength bands. Because of the flexibility in the choice of the amplification window that depends only on the pump wavelength (Perlin and Winful, 2002), and of the currently available higher pump power, Raman fiber amplifiers (RFA) have known deep investigations. Beside distributed RFA where the transmission fiber itself is used as the amplifying medium, one finds discrete RFA design, which is also used to compensate dispersion. Nevertheless, until now the fiber length required to provide reasonable gain was several kilometer long because of the relatively weak Raman gain efficiency of classical optical fiber already available (Soto and Olivares, 2004). However the parallel high fiber linear losses and potential lack of uniformity in the Raman gain of this new kind of fiber requires very careful design.

They have applied a technique that we developed to characterize the distribution of the gain in the fiber to determine optimal length of the fiber and pump power required to maximize the gain according to the pump and signal wavelength. In recent years Raman amplification has become an increasingly important technology for high performance optical networks (Bouteiller et al., 2004), complementing Erbium Doped Fiber Amplifier (EDFA) technology in many applications, and in others supplanting it altogether. The two main advantages of Raman amplification are the ability to use any type of fiber as an amplification medium, and the ability to amplify signals in any wavelength band using an appropriate pumping scheme (Wong et al., 2003). The ability to use any type of fiber as a gain medium has been successfully utilized for Distributed Raman Amplification, where amplification takes place inside the transmission

*Corresponding author. E-mail: ahmed_733@yahoo.com. Tel: +2 048-3660-617. Fax: +2 048-3660-617.

fiber itself. When combined with conventional lumped (discrete) amplifiers, such as EDFA's, this provides a significant improvement in the optical signal to noise ratio (OSNR) ratio of the transmitted optical signals, thus allowing longer reach and/or higher capacity networks. However, Raman technology can also be applied to lumped amplifiers, in which case the ability to amplify signals in any wavelength band can be used to construct Lumped Raman Fiber Amplifiers which operate in wavelength bands where EDFA technology is either inapplicable or relatively inefficient (Kung et al., 2003). It is more than 20 years since fiber-optic communications have been in commercial use and new technological developments are constantly being made. Several years ago wavelength-division multiplex (WDM) transmission using Erbium-doped fiber amplifiers became the main-stream technology for large-capacity long-haul systems, and more recently, to set new records, it has become indispensable to make use of Raman amplifiers, optimizing the dispersion characteristics of the transmission path. During the 1980s the Raman amplifier was extensively studied as a promising candidate for use in fiber-optic transmission but with the development of commercially viable EDFAs, they were allowed to languish for a period. When bit-rates were rising from 10 to 40 Gbit/sec (Pasquale and Meli, 2003), it was not possible to design systems that used only discrete amplifiers like EDFAs and the advantages of distributed Raman amplification, in which the transmission path as a whole is the amplifying medium, again came to be recognized. They may further say that the concept of multi-wavelength pumping, in which high-reliability laser diodes are used as the pump source to achieve adequate gain over a broad band, was advanced to extend the applicability of optical fiber Raman amplifiers. In conventional multi-wavelength Raman amplifiers, backward pumping is the configuration normally used. Backward pumping has a problem, however, in that when gain is flattened over a broad bandwidth, the wavelength-dependence of the noise figure becomes pronounced. Fiber Raman amplifiers have attracted a lot of recent attention for extending the optical telecommunications bandwidth and upgrade of current systems. Broadband gain can be obtained if multiple pumps are employed, and the gain profile can be flattened if the pump configuration is appropriately designed. Gain flatness can also be achieved with spectral filtering but with the addition of loss to the system. Traversing a fibre takes some time, an effect that may be exploited. Optical memories are often realized using a piece of fibre for short delays, while longer delays become very impractical since the propagation delay of a signal is only about 5 μsec/km, offering a capacity of 50 kb at 10 Gb/s for 1km of fiber used as a buffer. The capacity of an optical link may be increased by deploying a cable with several fibers in parallel, by using several wavelength channels in a single fibre, or by interleaving several bit streams into a high bit rate. These techniques are named space division multiplexing (SDM), wavelength division multiplexing (WDM) and time division multiplexing (TDM), respectively, and all of them are employed. An optical link may consist of several cables where each cable may include many fibers, in total a few thousands of fibers in parallel available for SDM. WDM networks are widely deployed and the market appears to be saturated, with a number of redundant dark fibers and free channels being available. Nevertheless (Mahmud, 2009), utilization of the networks constantly grows. Sites offering video-on-demand are huge capacity consumers, out of which you tube is an excellent example, and we need to be prepared to meet future demands for an even higher capacity. As the optical signal moves along a standard single mode fiber SSMF, it gets attenuated along the fiber and if the data speed is high enough (> 10 Gb/s), it gets distorted due to chromatic and polarization dispersions. So optical fiber amplifiers must be designed to amplify the signal along the fiber, the more the gain, the more span distance between amplifiers as long as the signal is not distorted due to high optical power. To make use of this great bandwidth, dense wavelength division multiplexing DWDM is used, but each type of optical fiber amplifier has different bandwidth. Optical transmission system design issues such as mid-span optically amplified distance, bandwidth enhancement can be assisted using Raman optical amplification (ROA) technology. ROA does not suffer from the limitations of EDFA in that it can be integrated with the transmission fibers, and pumped at any wavelength to provide wide gain bandwidth and gain flatness by employing a combination of different wavelength pumping sources. Different pumping configurations provide flexibility in the system for both distributed and discrete ROA (Felinsky and Korotkov, 2008). It offers a number of possible technical advancements to optically amplified long haul transmission infrastructure. In modern long haul fiber-optic communication systems, the transmission distance is limited by fiber loss and dispersion. Traditional methods to overcome this limitation, which use electrical conversion of the optical signal, such as repeaters to retransmit signals at progressive stages are becoming increasingly complex and expensive. In the 1990s, optical amplifiers, which directly amplified the transmission signal, became widespread minimizing system intricacies and cost. While upgrades in transmission fiber design in particular dispersion-compensating fibers (DCF) minimized linear phase distortions in the signal. In modern systems, existing EDFA lumped optical amplifiers are employed to ensure the quality of the transmitted optical signals. Recently, a renewed interest in Raman Fiber amplifiers (FRA) has been emerged as alternatives to Erbium-doped Fiber amplifiers. This has become feasible owing to development of high-power semiconductor laser diodes which are vitally needed as the sources for the FRAs. These amplifiers have some inherent benefits over the other types of optical amplifiers

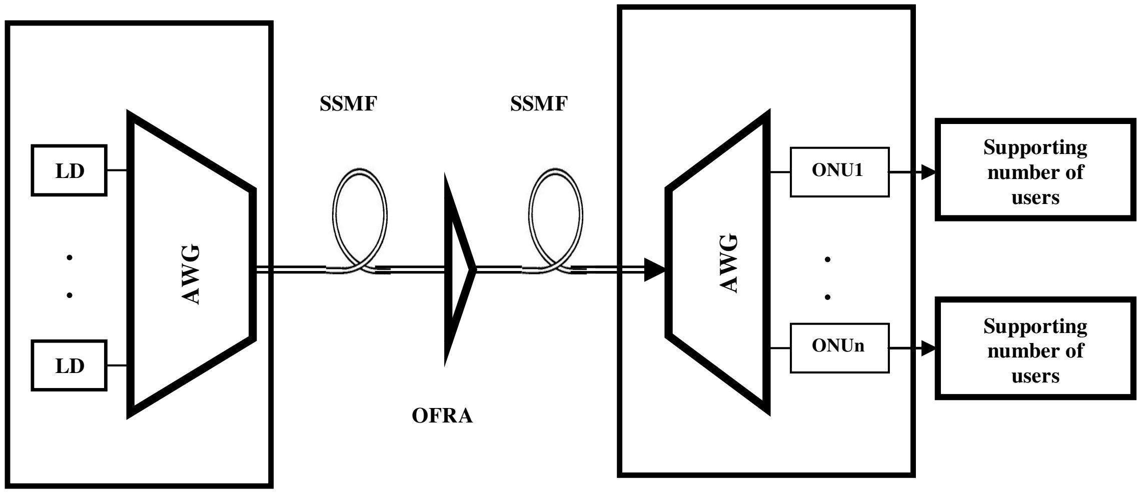

Figure 1. Advanced passive optical communication network model.

currently in use, most of all, for their broadband multi-pump gain spectrum which is fully malleable employing particular design schemes. Distributed FRAs are often used as optical LNAs before EDFAs where they also yield lower nonlinear effects and a decreased effective distance between repeaters as a result of their remarkable improvement in optical signal to noise ratio. Discrete FRAs as well offer a broadband characteristic which enables dramatic increase in the potential capacity of optical networks, breaking its upper bounds due to limited bandwidth of rare doped fiber amplifiers. In order to benefit these features of FRAs and obtain acceptable performance, different regimes which affect the evolution of pumps and signals during their propagation along the fiber should be measured (Lee et al., 2009).

In the present work, we have been modeled and analyzed parametrically and numerically the different pumping direction configurations to provide flexibility in the optical system for optical fiber Raman amplifiers for employment in ultra high speed long haul transmission and high capacity optical access network applications. We have developed the investigations of optical fiber Raman amplifiers for different transmission silica fibers for signal propagation over ultra long haul transmission bit rates and distance in advanced optical communication networks. We have deeply studied the investigation of the soliton transmission technique under the temperature sensing and optical signal variations to handle the bit rate and product either per link or per channel in all pumping direction of Raman amplifications

SIMPLIFIED ADVANCED OPTICAL COMMUNICATION NETWORK MODEL

The deployment of an optical network layer with the same flexibility because it is more economical and allows a better performance in the bandwidth utilization. The optical demultiplexer which divides the light beam in to different optical channels adjustable at different specific wavelengths and then directed to optical network units (ONUs) and finally directed to the minimum or maximum number of supported users or subscribers depend on the process of add or drop multiplexing. The optical fiber Raman amplifier (OFRA) is the important station for strength the optical signals through standard single mode fiber (SSMF) in order to allow ultra long haul transmission in advanced optical communication networks. A DWDM system can be described as a parallel set of optical channels, each using a slightly different wavelength, but all sharing a single transmission medium or fiber. Figure 1 illustrates the functionality of a multi-channel DWDM transmission system when various 5 - 40 Gbit/sec signals are fed to optical transmission modules. An optical arrayed waveguide grating multiplexer then bunches these optical signals together on one fiber and forwards them as a multiplexed signal to an optical fiber Raman amplifier. Depending on path length and type of fiber used, one or more optical fiber Raman amplifiers can be used to boost the optical signal for long fiber links. At termination on the receiving end, the optical signals are preamplified, then separated using optical filters and arrayed waveguide grating demultiplexers before being converted into electrical signals in the receiver modules. For bi-directional transmission, this produce must be duplicated in the opposite direction to carry the signals in that particular direction. If the OFRA is employed in the forward pumping direction provides the lowest noise figure. In fact, the noise is sensitive to the gain and the gain is the highest when the input power is the lowest. But if it is employed in the backward pumping provides the highest saturated output power. And finally, if it is employed in bi-directional pumping scheme has a higher performance than the other two by combining the lowest noise figure and the highest output power advantageous although it requires two pump lasers. In addition, in this scheme the small signal gain is uniformly distributed along the active fiber. Raman amplification in silica fiber is a promising means for extending the operational range of optical telecommunication systems to wavelengths beyond those covered by erbium-doped fiber amplifiers. Progress in pump laser sources, in particular, in cascaded Raman fiber lasers, has made reliable and efficient Raman amplifiers a reality. These amplifiers are not confined to any particular wavelength but can operate throughout the low-loss window of optical fiber from 1.2 - 1.7 µm.

MODELING AND EQUATIONS ANALYSIS

Optical fiber Raman amplifier employing the bi-directionally pumping scheme is able to achieve higher optical signal to noise ratio (OSNR) compared to the one using the backward pumping scheme. However there is a tradeoff between forward and backward amplification because too much amplification near the input end will result in higher path-averaged power in the span, and hence larger nonlinear penalties. It is assumed that the optical power of the first pump source is S P_P and the second source pump is (1-S) P_P respectively, where P_P is the pump power and S is a coefficient showing the power that is being pumped in the signal direction. The evolution of the optical signal power (P_s) and the power of the pump source propagating along the fiber cable can described by different equations called propagation equations. The optical signal and pump power can be expressed as follows (Jordanova, and Topchiev, 2008):

$$\pm\frac{dP_P}{dz}=-\frac{\nu_P}{\nu_S}g_R\,P_P P_S-\alpha_P P_P \quad , \tag{1}$$

$$\frac{dP_S}{dz}=g_R\,P_P P_S-\alpha_S P_S \quad , \tag{2}$$

Where g_R in $W^{-1}m^{-1}$is the Raman gain coefficient of the fiber cable length, α_S and α_P are the attenuation of the signal and pump power in silica-doped fiber, v_S and v_P are the signal and pump frequencies. The signs of "+" or "-" are corresponding to forward and backward pumping. Since P_P » P_S, the first term in Equation (1) is negligibly low compared with the second and its influence can be neglected. Therefore, Equation (1) can be solved when both sides of the equation are integrated. When using forward pumping (S = 1), the pump power can be expressed as (Jordanova and Topchiev, 2008):

$$P_P(z)=P_P(0)\exp(-\alpha_P L) \quad , \tag{3}$$

In the backward pumping case (S = 0) the pump power is respectively equal to:

$$P_P(z)=P_P(0)\exp\left[-\alpha_P\,(L-z)\right] \quad , \tag{4}$$

In the general case, when a bi-directional pumping (Raghuawansh et al., 2006) is used (S = 0 - 1) the laser source work at the same wavelength at different pump power. Therefore to calculate the pump power at point z it can be used:

$$P_P(z)=SP_P(0)\exp(-\alpha_P\,L)+(1-S)P_P(0)\exp\left[-\alpha_P\,(L-z)\right], \tag{5}$$

If the values of P_P are substituted in differential Equation (2), and it is integrated from 0 to L for the signal power in the forward and the backward pumping can be written as:

$$P_S(L)=P_S(0)\exp\left[g_R\,S\,P_0\,\frac{1-\exp(-\alpha_P z)}{\alpha_P}-\alpha_S z\right]=G_F P_S(0), \tag{6}$$

$$P_S(L)=P_S(0)\exp\left[\begin{array}{l} g_R(1-S)P_0\,x\,\dfrac{\exp(-\alpha_P L)(\exp(\alpha_P z)-1)}{\alpha_P} \\ -\alpha_S z \end{array}\right] = G_B P_S(0), \tag{7}$$

Where; G_F, G_B are the net gain in the forward and backward pumping respectively. The maximum allowed transmit power per channel, as a function of fiber cable link length can be expressed as follows (Jalali, 2006):

$$P_{Transmitted}\;\langle\;\frac{4\times10^4}{N_{ch}(N_{ch}-1)\Delta\lambda_S\,L} \tag{8}$$

Where N_{ch} be the number of channels, $\Delta\lambda_S$ be the channel spacing in nm, and L is to be the length of the fiber cable link in km. The maximum transmitted power per channel deceases. If the spacing is fixed, the power launched decreases with N_{ch} inversely with a square term (Jalali, 2006). The SSMF cable is made of the silica material which the investigations of the spectral variations of the waveguide refractive-index (n) require Sellemeier equation (Fleming, 1985):

$$n^2=1+\frac{H_1\lambda^2}{\lambda^2-H_2^2}+\frac{H_3\lambda^2}{\lambda^2-H_4^2}+\frac{H_5\lambda^2}{\lambda^2-H_6^2} \tag{9}$$

The parameters of Sellmeier equation coefficients for pure silica material, as a function of ambient temperature as (Fleming, 1985): H_1= 10.668193, H_2= 0.03015485 * $(T/T_0)^2$, H_3= 0.00334218, H_4= 1.13411235 * $(T/T_0)^2$, H_5= 1.54133408, H_6= 0.001104. Where T is the temperature of the material, ℃, and T_0 is the reference temperature and is considered as 27 ℃. Then the second differentiation of Equation (9) w. r. t λ yields:

$$\frac{d^2 n}{d\lambda^2} = \frac{1}{n}\left[\frac{H_1\left(\lambda^2 - H_2^2\right) - 4\lambda^2}{\left(\lambda^2 - H_2^2\right)^3} + \frac{H_3\left(\lambda^2 - H_4^2\right) - 4\lambda^2}{\left(\lambda^2 - H_4^2\right)^3} + \frac{H_5\left(\lambda^2 - H_6^2\right) - 4\lambda^2}{\left(\lambda^2 - H_6^2\right)^3}\right] \quad (10)$$

The total bandwidth is based on the total chromatic dispersion coefficient D_t where:

$$D_t = D_m + D_w \quad (11)$$

Both D_m, and D_w are given by (for the fundamental mode):

$$D_m = -\frac{\lambda}{c}\left(\frac{d^2 n}{d\lambda^2}\right), \quad n\sec/nm.km \quad (12)$$

$$D_w = -\left(\frac{n_{cladding}}{c\,n}\right)\left(\frac{\Delta n}{\lambda}\right)Y, \quad n\sec/nm.km \quad (13)$$

Where; c is the velocity of the light, 3 x 10^8 m/s, n is the refractive-index of the fiber cable core, Y is a function of wavelength, the relative refractive-index difference Δn is:

$$\Delta n = \frac{n^2 - n_{cladding}^2}{2n^2}, \quad (14)$$

In any infinitesimal segment of fiber, dispersion on one hand and non linearity of the refractive-index on the other hand produce infinitesimal modulation angles which exactly compensate reciprocally. Under such conditions the pulse shape is the same everywhere. All this provided that a soliton waveform be used with a peak power (Yabre, 2000):

$$P_1 = \frac{\Delta\lambda^3 D_t A_{eff}}{4\pi^2 c\, n_2\, \Delta\tau^2}, \quad (15)$$

Where n_2 is the nonlinear Kerr coefficient, 2.6 x 10^{-20} m^2/Watt, Δλ is the spectral line width of the optical source in nm, P_1 is the peak power in watt, A_{eff} is the effective area of the cable core fiber in μm^2, D_t is the total chromatic dispersion coefficient in n seconds/nm.km. Then the pulse intensity width in n seconds is given by:

$$\Delta\tau = \sqrt{\frac{\Delta\lambda^3 D_t\, A_{eff}}{4\pi^2\, P_1\, n_2\, c}}, \quad n\sec \quad (16)$$

Then the Soliton transmission bit rate per optical network channel or unit is given as (Abd El-Naser et al., 2009):

$$B_{rsc} = \frac{1}{10\ \Delta\tau} = \frac{0.1}{\Delta\tau}, \quad Gbit/\sec/channel \quad (17)$$

Then the Soliton transmission bit rate per link is given as follows:

$$B_{rsl} = \frac{0.1 * N_{link}}{\Delta\tau}, \quad Gbit/\sec/link \quad (18)$$

Where; N_{Link} is the total number of links in the fiber cable core, and N_{ch} is the total number of channels. The available soliton transmitted bit rate B_{rs} is compared as the fiber cable length, L, and consequently the soliton product P_{rsc} per channel is computed as the following expression:

$$P_{rsc} = 1000 * B_{rsc} * L, \quad Gbit.km/\sec \quad (19)$$

$$P_{rsl} = 1000 * B_{rsl} * L, \quad Gbit.km/\sec \quad (20)$$

Where; B_{rsc} is the soliton transmission bit rate per channel in Gbit/sec, B_{rsl} is the soliton transmission bit rate per link in Gbit/sec, and L is the fiber cable length in km.

RESULTS AND DISCUSSION

We have investigated parametrically the UWB Raman amplifiers in advanced optical networks in the interval of 1.45 - 1.65 μm under the set of affecting. The numerical data of our system model design are employed to obtain the best performance characteristics of optical fiber Raman amplifiers in advanced optical networks for upgrading network efficiency by increasing transmission bit rates, distances and network capacity to support maximum number of users or subscribers as follows:

1.5 ≤ λ_{si}, optical signal wavelength, μm ≤ 1.65, 1.4 ≤ λ_p, pumping wavelength, μm ≤ 1.55, α_{si} = 0.25 dB/km, α_P= 0.3 dB/km, Pumping power: P_P = 0.22 Watt/pump, 2 ≤ P_{si}, optical signal power, mwatt ≤ 20, 25 ≤ambient temperature, T, ℃ ≤ 45, T_0 = 27℃, A_{eff}= 85 μm^2, N_L: total number of links up to 24 links, $\Delta\lambda_s$ =0.2 nm, 0.001 ≤ Δn, relative refractive-index difference ≤ 0.009, N_t: total number of channels up to 600 channels, Raman gain coefficient: g_R = 0.7 W^{-1}. km^{-1}. Based on the series set of Figures (2 - 22), the obtained facts are assured to present the high performance of Raman amplifiers in advanced op-

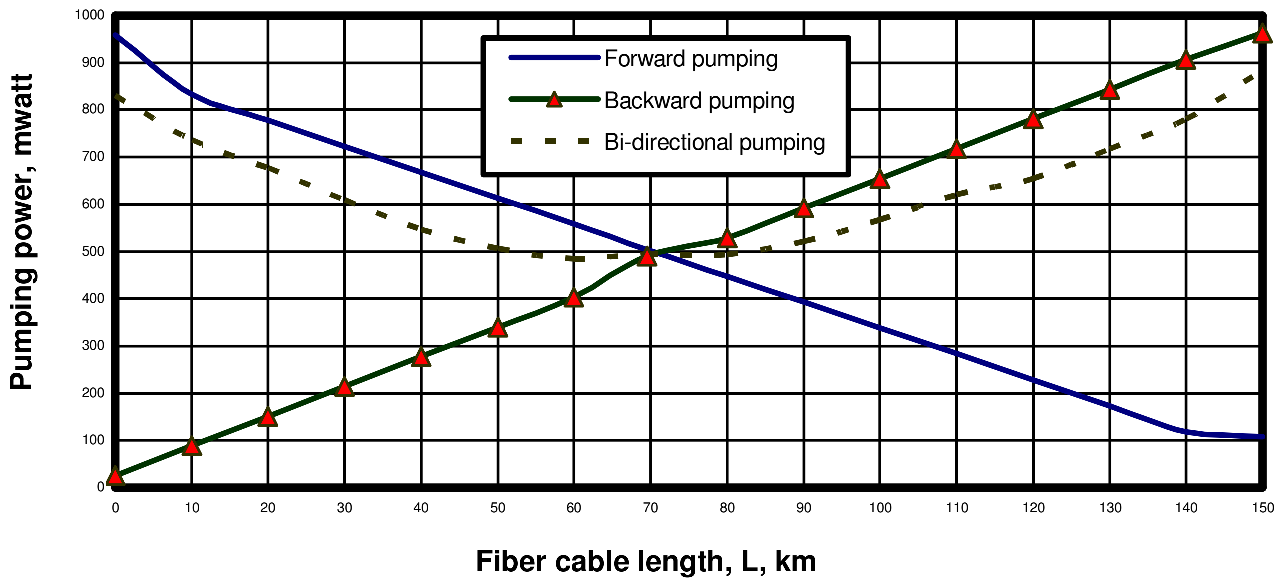

Figure 2. Variations of the pumping power with the fiber cable length at the assumed set of parameters.

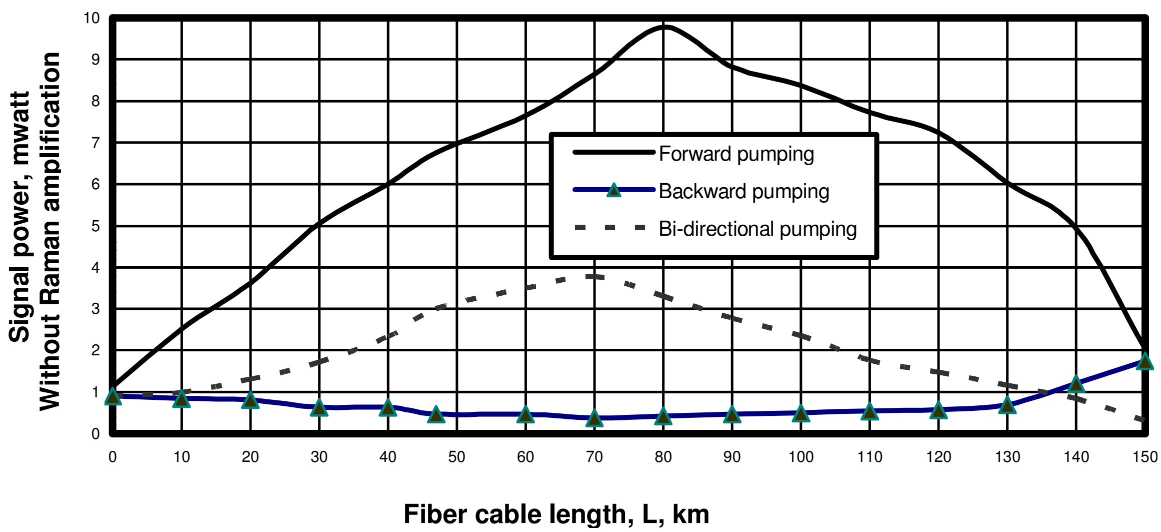

Figure 3. Variations of the signal power with the fiber cable length at the assumed set of parameters.

tical networks to present the highest transmission bit rates and distances for different pumping direction as:

(1) As shown in Figure 2, has indicated that the pumping power evolution along the total standard single mode fiber (SSMF) cable length for forward, backward, and bi-directional pumping direction configurations. We have observed that as the fiber cable length increases, pumping power should be also increased in the backward direction. While in the forward pumping, as the fiber cable length increases, pumping power decreases and in the bi-directional pumping, as the fiber cable length increases, pumping power decreases in the side length of fiber cable, and increases in the other side of fiber cable length.

(2) Figure 3 has demonstrated that with no Raman amplification. In the forward direction configuration, there is a large gain in power at the beginning of fiber cable length. This results in increasing effects of nonlinearities in the fiber cable length, because of the power dependence of the refractive-indices of the core and cladding material. In the backward direction configuration, the gain occurs towards the end of the fiber cable after the substantial power loss. This power loss will increase the possibility of noise altering the quality of the signal. The bi-directional configuration has demonstrated the balance results in

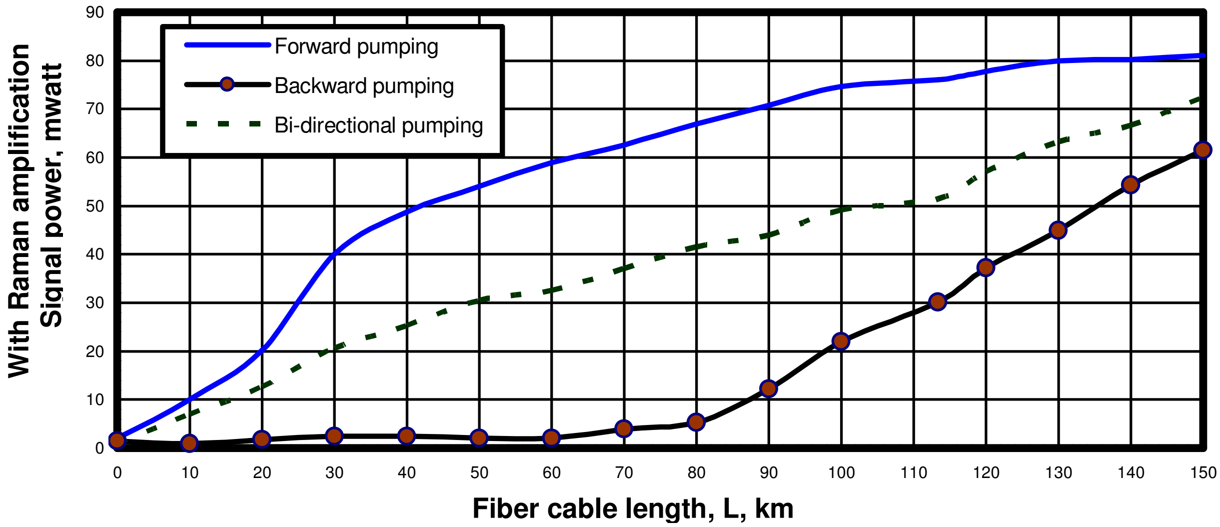

Figure 4. Variations of the signal power with the fiber cable length at the assumed set of parameters.

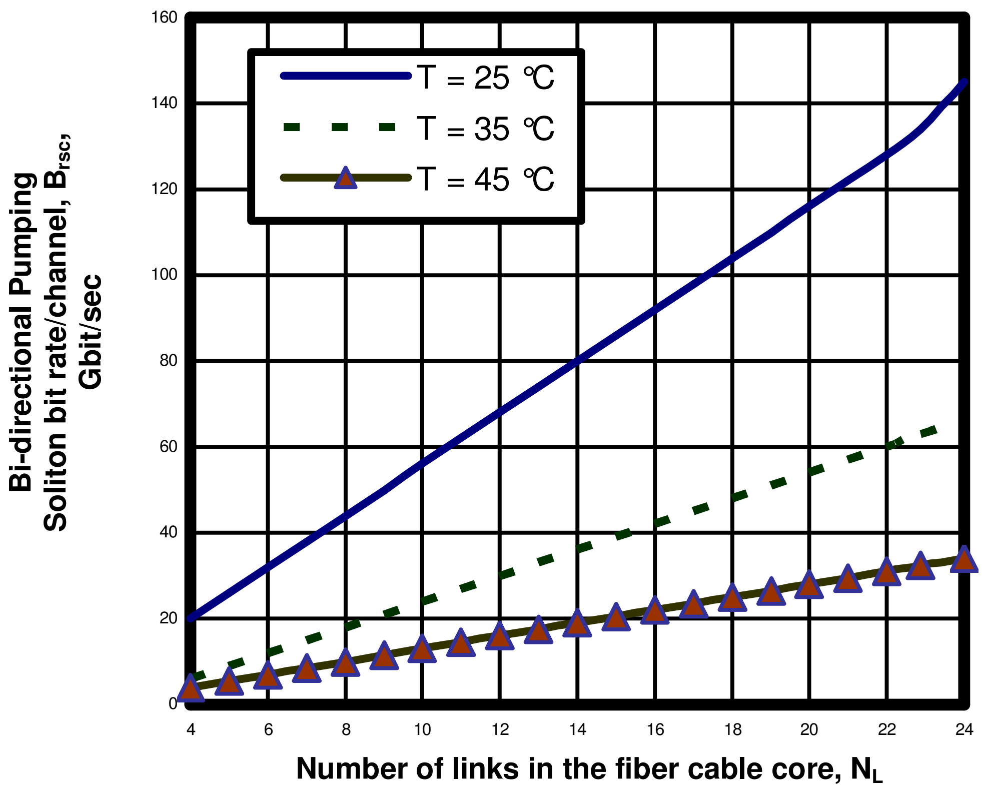

Figure 5. Variations of the soliton bit rate per channel with the number of links in the fiber cable core at the assumed set of parameters.

terms of noises and nonlinearities.

(3) It is observed from Figure 4, we have demonstrated the importance of the Raman gain evolution over the total SSMF cable length, due to Raman amplification for forward, backward, and bi-directional configurations. It is evident that in the forward and bi-direction pumping present the highest signal power gain than the backward pumping.

(4) The series of Figures (5 - 7) has indicated that, as the number of links in the fiber cable core increases, the soli-

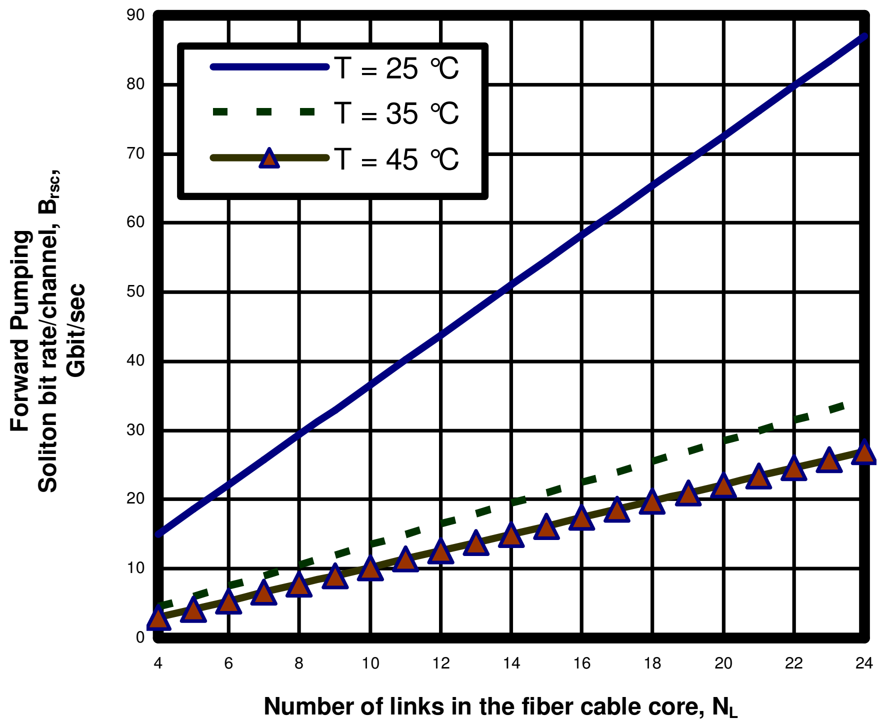

Figure 6. Variations of the soliton bit rate per channel with the number of links in the fiber cable core at the assumed set of parameters.

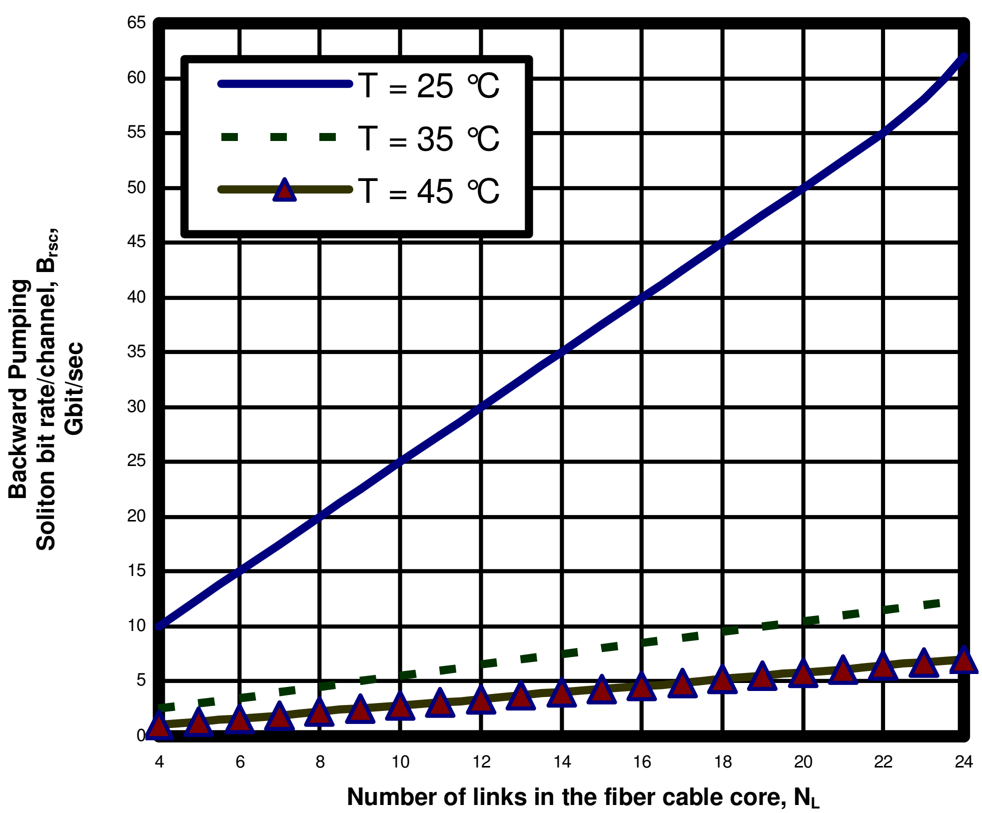

Figure 7. Variations of the soliton bit rate per channel with the number of links in the fiber cable core at the assumed set of parameters.

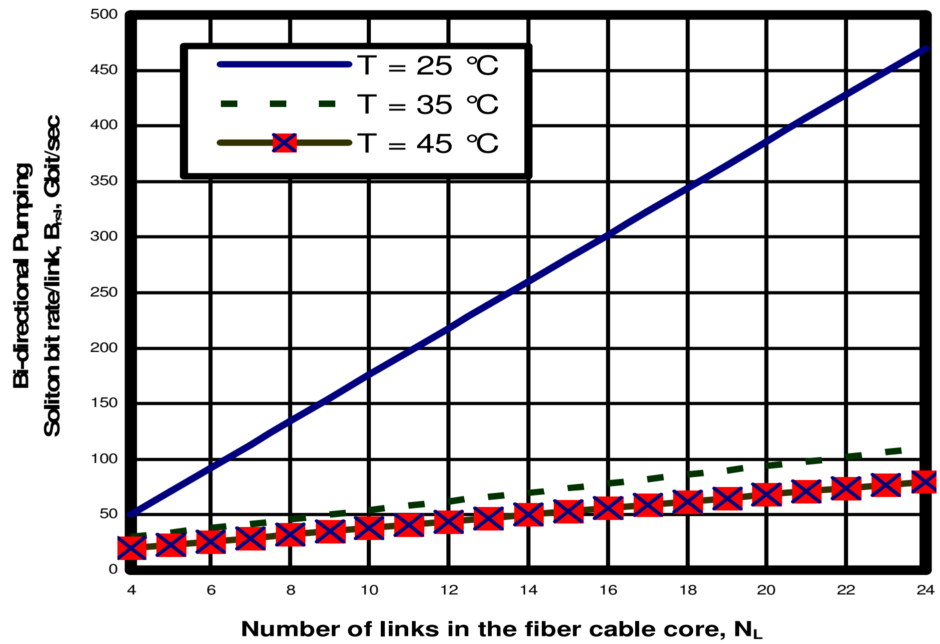

Figure 8. Variations of the soliton bit rate per link with the number of links in the fiber cable core at the assumed set of parameters.

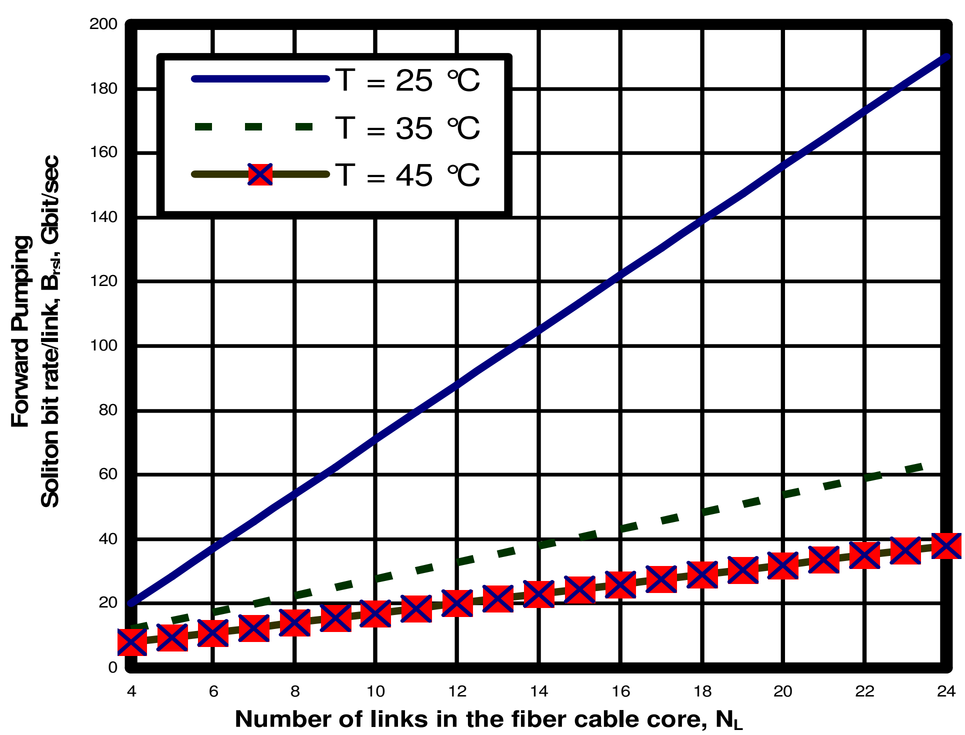

Figure 9. Variations of the soliton bit rate per link with the number of links in the fiber cable core at the assumed set of parameters.

soliton bit rate per channel also increases at the same ambient temperature. But as the ambient temperature increases, the soliton bit rate per channel decreases at the same number of links in the fiber cable core.

(5) Figures (8 - 10) have demonstrated that as the number of links in the fiber cable core increases, the soliton

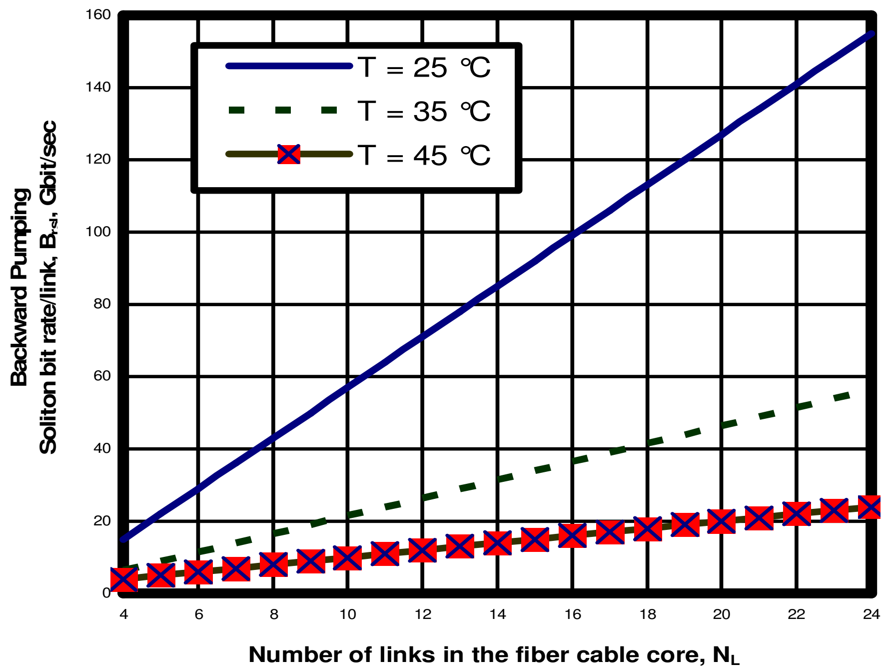

Figure 10. Variations of the soliton bit rate per link with the number of links in the fiber cable core at the assumed set of parameters.

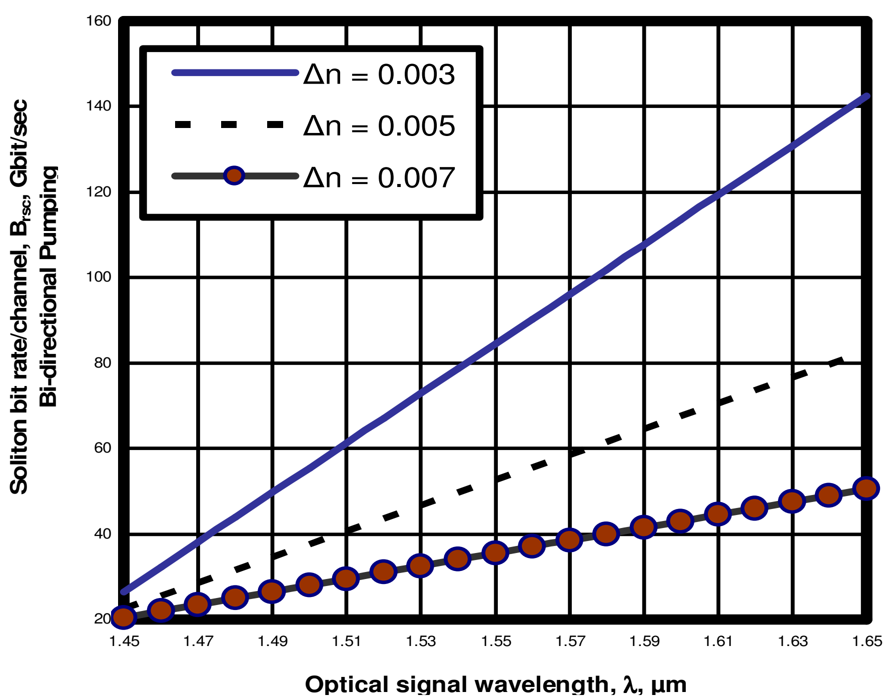

Figure 11. Variations of the soliton bit rate per channel with the optical signal wavelength at the assumed set of parameters.

soliton bit rate per link also increases at the same ambient temperature. But as the ambient temperature increases, the soliton bit rate per link decreases at the same number of links in the fiber cable core.

(6) As shown in Figures (11 - 13), we have demonstrated that as the optical signal wavelength increases, the soliton

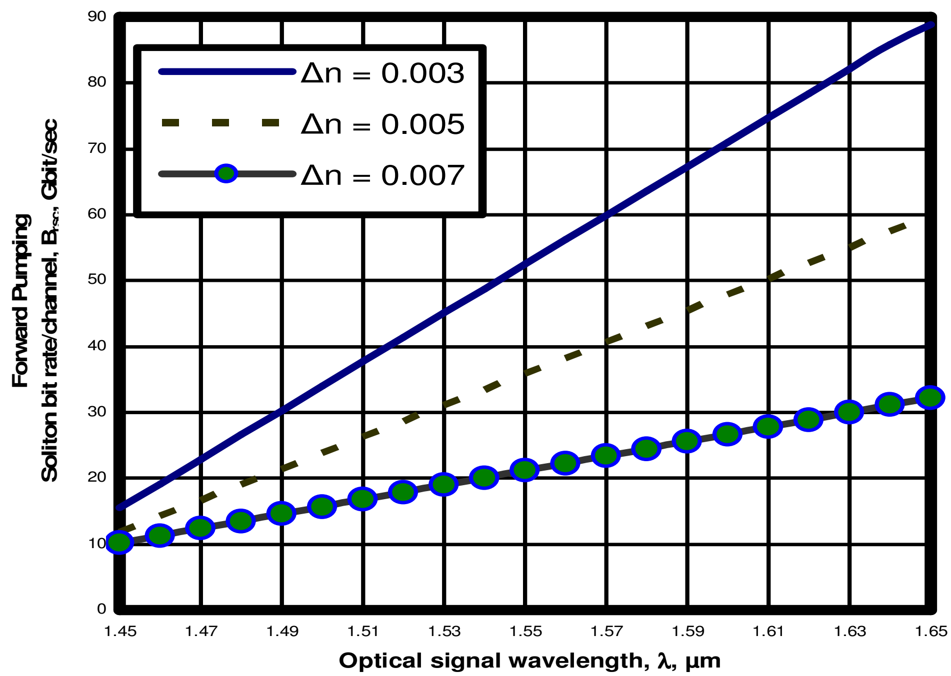

Figure 12. Variations of the soliton bit rate per channel with the optical signal wavelength at the assumed set of parameters.

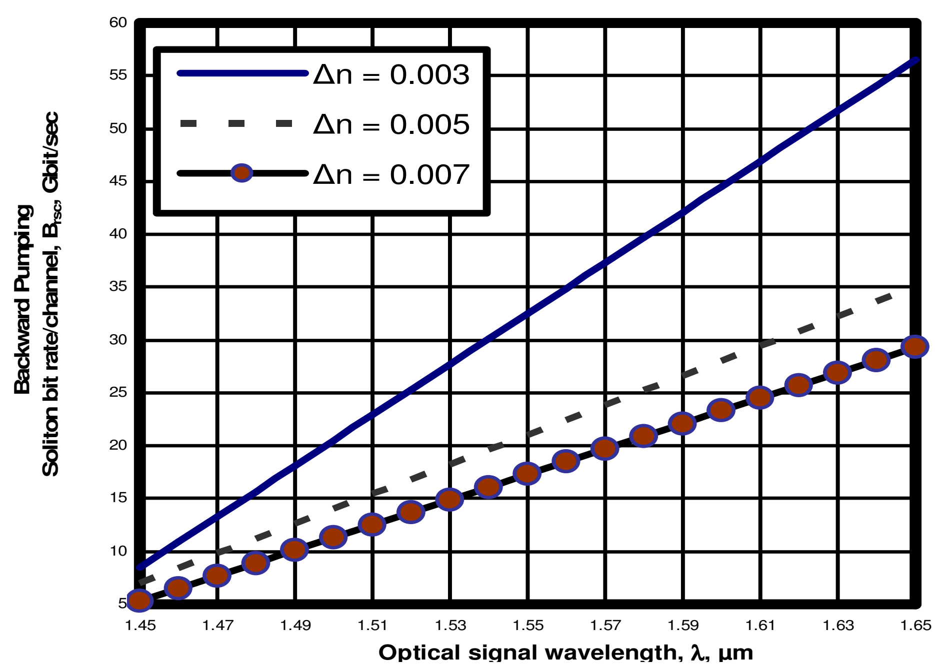

Figure 13. Variations of the soliton bit rate per channel with the optical signal wavelength at the assumed set of parameters.

bit rate per channel also increases at the same relative refractive-index difference Δn. But as Δn increases, soliton bit rate per channel decreases at the same optical signal wavelength for different pumping direction configurations. Moreover, in the case of bi-directional pumping configuration presents the highest bit rates per channel than the other two pumping direction configurations.

(7) Figures (14 - 16) have proved that as the number of

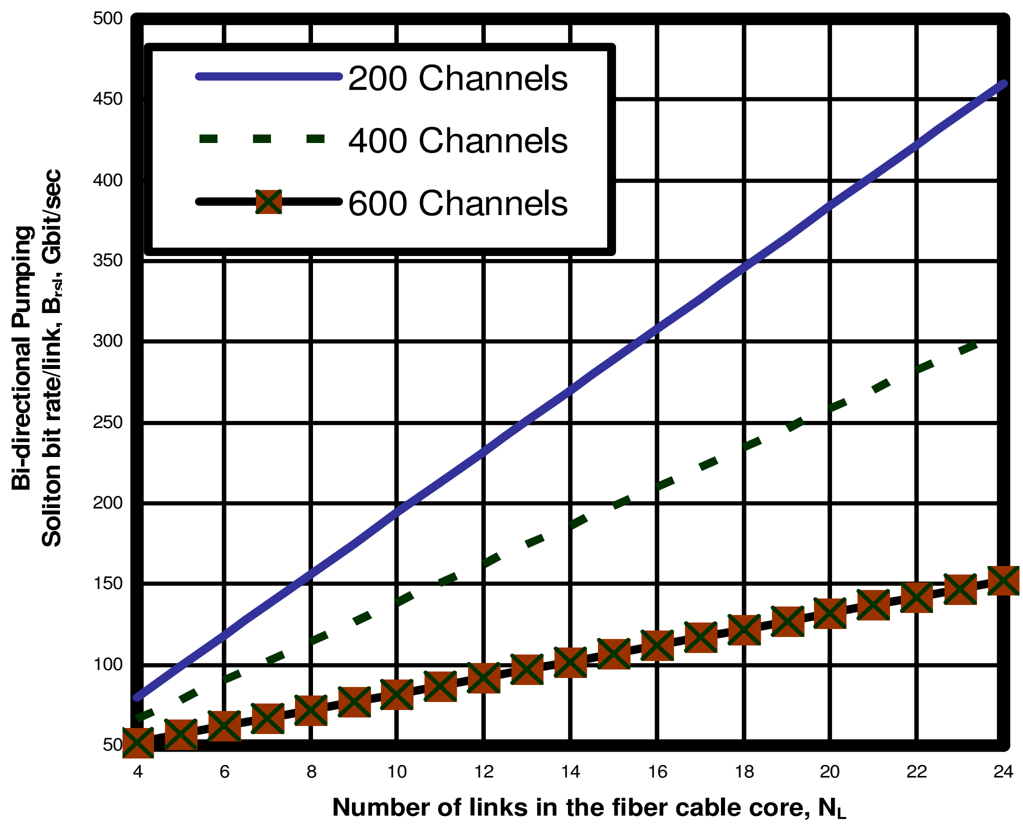

Figure 14. Variations of the soliton bit rate per link with the number of links in the fiber cable core at the assumed set of parameters.

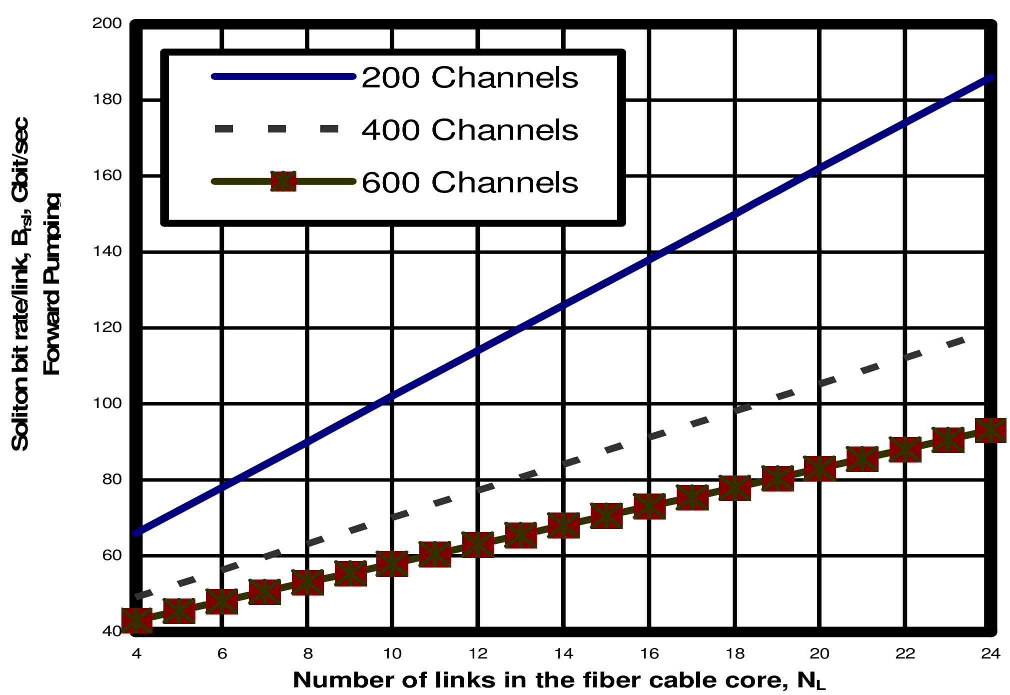

Figure 15. Variations of the soliton bit rate per link with the number of links in the fiber cable core at the assumed set of parameters.

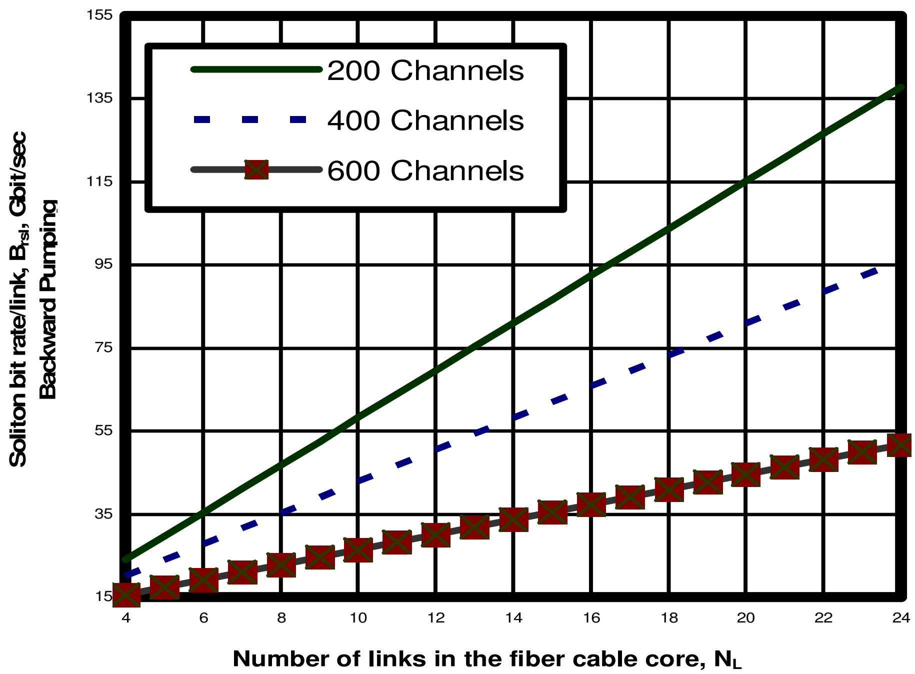

Figure 16. Variations of the soliton bit rate per link with the number of links in the fiber cable core at the assumed set of parameters.

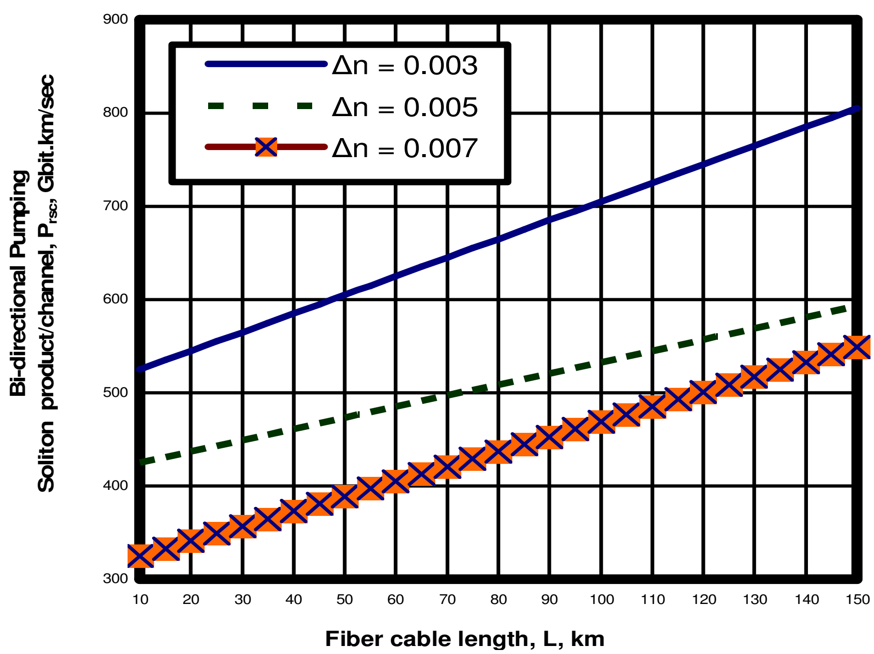

Figure 17. Variations of the soliton product per channel with the fiber cable length at the assumed set of parameters.

links in the fiber cable core increases, soliton bit rate per link also increases at the same number of transmitted channels, and as the number of transmitted channels increases, the soliton bit rate per link decreases at the same number of links in the fiber cable core. But in the case of bi-direction pumping configuration presents the highest bit rates per link than the other two pumping direction configurations.

(8) The series of Figures (17 - 19) have indicated that as the fiber cable length increases, soliton product per chan-

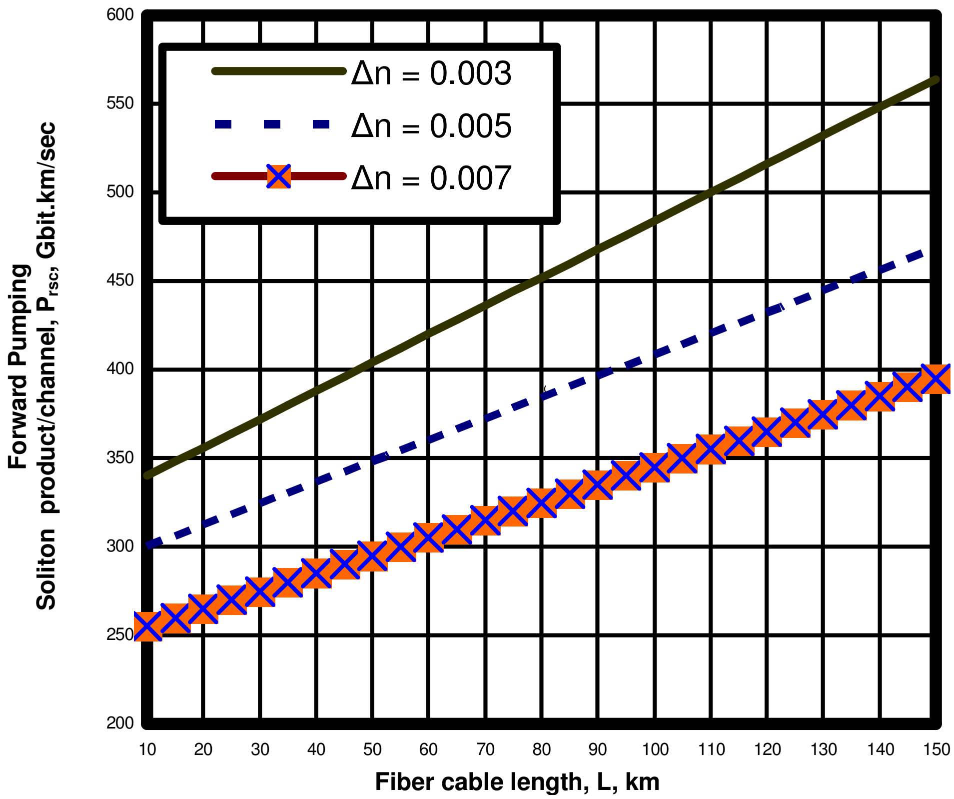

Figure 18. Variations of the soliton product per channel with the fiber cable length at the assumed set of parameters.

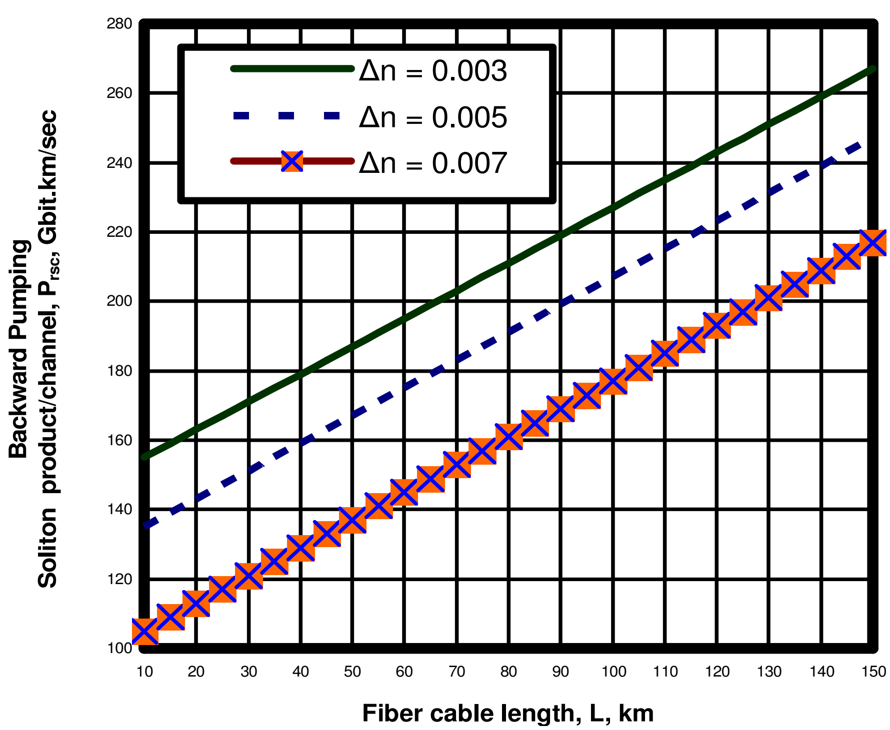

Figure 19. Variations of the soliton product per channel with the fiber cable length at the assumed set of parameters.

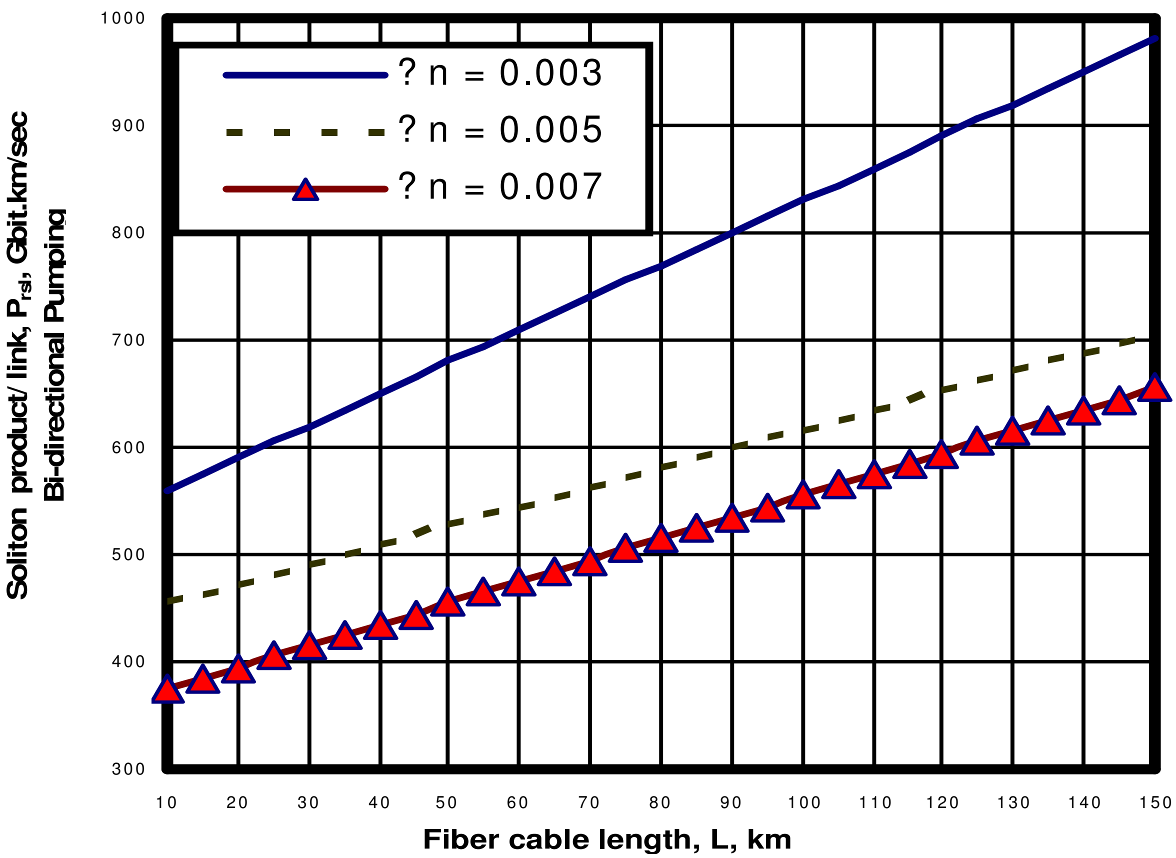

Figure 20. Variations of the soliton product per link with the fiber cable length at the assumed set of parameters.

nel also increase at the same refractive refractive-index difference Δn. But as the refractive refractive-index difference Δn increases, the soliton product per channel decreases at the same fiber cable length. But in the case of bi-direction pumping configuration presents the highest soliton product per channel than the other two pumping direction configurations.

(9) As shown in the series of Figures (20 - 22) have assured that as the fiber cable length increases, soliton product per link also increases at the same refractive refractive-index difference Δn. But as the refractive refractive-index difference Δn increases, the soliton product per link decreases at the same fiber cable length. Moreover, in the case of bi-direction pumping configuration presents the highest soliton product per link than the other two pumping direction configurations.

Conclusion

In a summary, we have investigated and analyzed numerically and parametrically the optical fiber Raman amplifiers for ultra long haul transmission optical high speed optical communication systems in advanced optical communication networks. We have demonstrated in our major interest the importance role of optical fiber Raman amplifiers to strength the optical signal power in the forward, backward, and bi-directional pumping direction configurations and thus allowing longer transmission distances, higher capacity, and maximum transmission bit rates either per link or per channel. Thus we have assured that the importance employment of the bi-directional pumping configuration for Raman amplification technique under the effect of the ambient temperature variations along the fiber cable yields the highest soliton bit rate and product either per channel or per link, therefore we can get the maximum B.W-distance product through ultra long haul transmission distances in advanced optical communication networks within bi-directional pumping configuration. It is evident that the higher of the ambient temperature along fiber cable core, the lower of soliton bit rate and product either per link or per channel. Therefore, it is evident that the employment of Raman amplification technique within SSMF in the temperature range variations of 25℃ -30℃ yields the highest soliton transmission bit rates and products either per link or per channel to support maximum number of users.

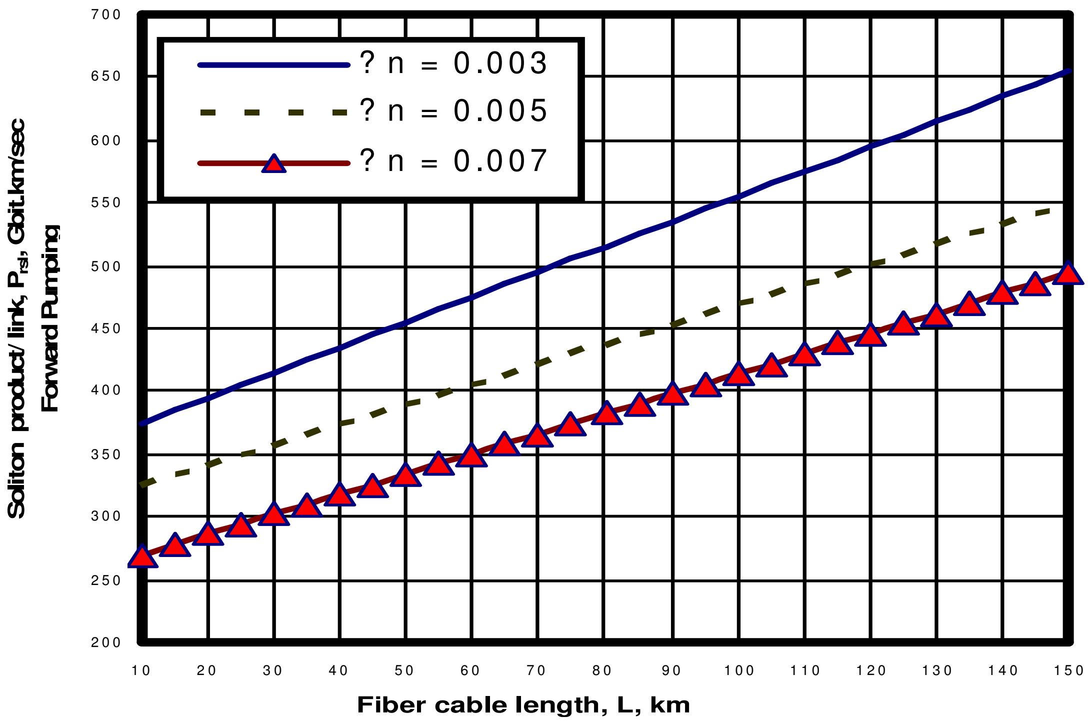

Figure 21. Variations of the soliton product per link with the fiber cable length at the assumed set of parameters.

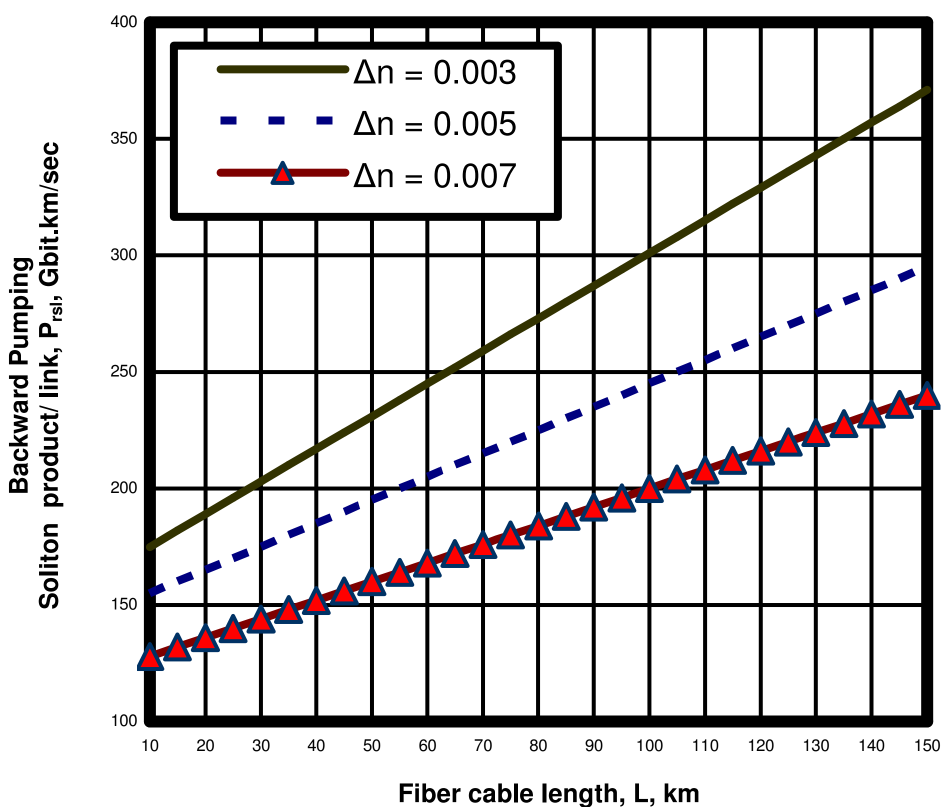

Figure 22. Variations of the soliton product per link with the fiber cable length at the assumed set of parameters.

REFERENCES

Islam MN (2002). “Raman Amplifiers for Telecommunications, Topics in Quantum Electronics, J. Select. 8(3): 548-559.

Perlin V, Winful HG (2002). “Optimal Design of Flat-Gain Wide-Band Fiber Raman Amplifiers,” J. Lightwave Technol. 20(2): 250-254.

Soto H, Bellingham WA, Olivares R (2004). “Optimal Design Based on Genetic Algorithm of Distributed Fiber Raman Amplifier Cascades” 5th Iberoamerican Meeting on Optics Proceedings of SPIE 5622: 364-367.

Bouteiller J, Leng L, Headley C (2004). “Pump-Pump Four-Wave Mixing in Distributed Optical Raman Amplified Systems,” J. Lightwave Technol. 22(3): 723-732.

Wong W, Chen C, Ho M, Lee H (2003). “Phase-Matched Four-Wave Mixing Between Pumps and Signals in a Copumped Raman Amplifier,” IEEE Photon. Technol. Lett. 15(2): 209-211.

Kung T, Chang C, Dung J, Chi S (2003). “Four-Wave Mixing Between Pump and Signal in a Distributed Optical Raman Amplifier,” J. Lightwave Technol. 21(5): 1164-1170.

Pasquale F, Meli F (2003). “New Raman Pump Module for Reducing Pump-Signal Four-Wave-Mixing Interaction in Co-Pumped Distributed Raman Amplifiers,” J. Lightwave Technol. 21(8): 1742-1748.

Mahmud W (2009). “Optical Fiber Amplifiers Review,” Inter. J. Commum. Networks. Info. Sec (IJCNIS) 1(1): 42-47.

Felinsky GS, Korotkov PA (2008). “Raman Threshold and Optical Gain Bandwidth in Silica Fibers J. Semiconductor Physics, Quantum Electronics, and Optoelectronics 11(4): 360-363.

Lee BG, Biberman A, Tuner AC, Foster MA, Lipson M, Gaeta AL, Bergman K (2009). “Demonstration of Broadband Wavelength Conversion at 40 Gb/sec in Silicon Waveguides,” IEEE Photonics Technol. Lett. 21(3): 182-184.

Jordanova LT, Topchiev VI (2008). “Improvement of the Optical Channel Noise Characteristics Using Distributed Raman Amplifiers,” ICEST 12(5): 20-23.

Raghuawansh S, Guta V, Denesh V, Talabattula S (2006). “Bi-directional Optical Fiber Transmission Scheme Through Raman Amplification: Effect of Pump Depletion,” J. Indian Inst. Sci. 5(2): 655-665.

Jalali B (2006). “Raman Based Silicon Photonics,” IEEE J. Sel. Top. Quantum Electron 12(3): 412-423.

Fleming W (1985). “Dispersion in GeO_2-SiO_2 Glasses,” Appl. Optics 23(24): 4486-4493.

Yabre G (2000). “Theoretical Investigation on the Dispersion of Graded-Index Polymer Optical Fiber, J. Lightwave. Technol. 18(16): 869-882.

Abd El-Naser Mohamed A, Abd El-Fattah Saad A, Ahmed Nabih Zaki Rashed (2009). “High Channel Arrayed Waveguide Grating (AWG) in Wavelength Division Multiplexing Passive Optical Networks (WDM-PONs),” IJCSNS Int. J. Comp. Sci. Network Sec. 9(1): 253-259.