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NEW TRENDS OF FORWARD FIBER RAMAN AMPLIFICATION FOR DENSE WAVELENGTH DIVISION MULTIPLEXING (DWDM) PHOTONIC COMMUNICATION NETWORKS

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Abstract- The technology of dense wavelength-division multiplexing (DWDM) has recently resulted in a considerable increase in the transmission capacity of fiber-optic communication systems up to several terabits per second. The further improvement of the transmission capacity of such systems can be achieved through the expansion of the spectral range of WDM transmission toward the short-wavelength region. Therefore this present paper has proposed and investigated the new trends and progress of fiber Raman amplification for dense wavelength division multiplexing photonic communication networks over wide range of the affecting parameters. As well as we have deeply studied the transmission distances and transmission bit rates within Raman amplification technique in forward pumping direction configuration through standard single-mode fiber using Shannon transmission technique to handle transmission bit rate and product per channel in this direction for upgrading network performance and efficiency to provide maximum amount of transmission data rate to the supported maximum number of users.

Keywords: Photonic Networks, Raman Amplification, Forward Direction, Transmission Data Rate, DWDM.

I. INTRODUCTION

Optical amplifiers are key elements of any fiber-optic communication system. Even though modern optical fibers have losses below 0.2 dB/km, a repeated amplification of the transmitted signal to its original strength becomes necessary at long enough distances [1]. One solution for signal regeneration is the conversion of the optical signal into the electrical domain and subsequent re-conversion into a fresh optical signal. However, purely optical amplifiers are usually preferred. They simply amplify the electromagnetic field of the signal via stimulated emission or stimulated-scattering processes in a certain optical frequency range.

The amplification process is essentially independent of the details of the spectral channel layout, modulation format or data rate of the transmission span [2], thus permitting the system operator to later re-configure these parameters without having to upgrade the amplifiers [3]. Multi-wavelength pumped Raman amplifiers (RAs) have attracted more and more attention in recent years [4]. In this type of amplification a widely used concept, for high capacity long distance wavelength division multiplexing (WDM) transmission systems was used. They have been already used in many ultra long-haul dense WDM (DWDM) transmission systems. It supports high bit rate data transmission over long fiber spans, due to its benefits such as proper gain and optical signal to noise ratio (OSNR). In addition, it can be used for increasing the bandwidth of Erbium doped fiber amplifiers (EDFAs) in hybrid systems.

Another important feature of RAs is its gain bandwidth, which is determined by pump wavelength. Multi-wavelength pumping scheme is usually used to increase the gain flattening and bandwidth for high capacity WDM transmission systems. In backward-pumped fiber Raman amplifiers, other noise sources, such as the relative intensity noise (RIN) transfer are minimized, because this scheme can suppress the related signal power fluctuation. OSNR of this excitation is tilted, and channels with longer wavelength have longer OSNR respect to the shorter wavelength channels [5, 6].

In the present study, we have integrated and deeply studied the fiber Raman amplification with the transmission media fibers, and pumped at any wavelength to provide wide gain bandwidth and improve optical signal to noise ratio of the transmitted optical signals in order to allow both ultra long transmission bit rate distance and high capacity in DWDM photonic networks in forward direction configuration over wide range of the affecting parameters.

II. SCHEMATIC VIEW OF DWDM PHOTONIC NETWORKS

Figure 1 shows multichannel DWDM transmission system when various 10 Gbit/sec signals are fed to optical transmission modules [7]. An optical DWDM coupler (multiplexer) then bunches these optical signals together on one fiber and forwards them as a multiplexed signal to an optical fiber amplifier (OFA). 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 of fiber. Depending on path length and type of fiber used, one pr more optical fiber amplifiers can be used to boost the optical signal for long fiber links. At termination on the receiving side, the optical signals are preamplified then separated by using optical filters (demultiplexer) before being converted to electrical signals in the receiving modules [8].

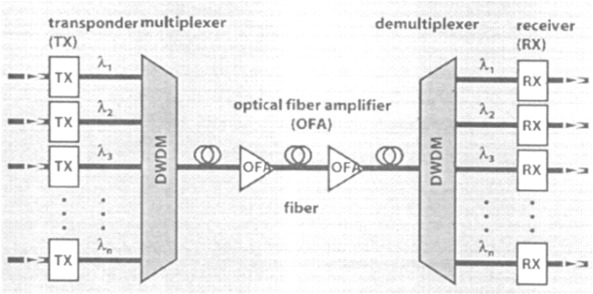

Figure 1. DWDM photonic networks

III. MODELING ANALYSIS

The signal and pump power interaction along fiber cable length can be expressed as [9]:

$$\frac{dP_S}{dL} = g_0\, P_P P_S - \alpha_S P_S \qquad (1)$$

$$+\frac{dP_P}{dL} = -\frac{\lambda_S}{\lambda_P} g_0\, P_P P_S - \alpha_P P_P \qquad (2)$$

where g_0 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, λ_S and λ_P are the signal and pump wavelengths. The sign of "+" is corresponding to forward pumping. Since $P_P \gg P_S$, therefore, Equation (2) can be solved when both sides of the equation are integrated. When using forward pumping (S=1), the pump power can be expressed as the following expression:

$$P_P(L) = P_P(0)\exp(-\alpha_P L) \qquad (3)$$

If values of P_P are substituted in differential Equation (1), and it is integrated from 0 to L for the signal power in the forward pumping direction can be written as:

$$P_S(L) = P_S(0)\exp\left[g_0\, S\, P_0\, \frac{1-\exp(-\alpha_P L)}{\alpha_P} - \alpha_S L\right] = G_F P_S(0) \qquad (4)$$

where G_F is the net gain in the forward pumping. With P_0 being the pump power at the input end. Hence the signal intensity at output of amplifier, fiber cable length L is determined by the following expression [10]:

$$P_S(L) = P_S(0)\exp\left(\frac{g_0\, P_0\, L_{eff}}{A_{eff}} - \alpha_S\, L\right) \qquad (5)$$

The effective length, L_{eff} is the length over which the nonlinearities still holds or Stimulated Raman scattering (SRS) occurs in the fiber and is defined as:

$$L_{eff} = \frac{1-\exp(-\alpha_P L)}{\alpha_P} \qquad (6)$$

Hence the amplification gain defined as the ratio of the power signal with and without Raman amplification, is given by the following expression:

$$G_A = \frac{P_S(L)}{P_S(0)\, \exp(-\alpha_S L)} \qquad (7)$$

Noise figure is the determination of the signal denigration over the length of the transmission span. It is the signal to noise ratio of input over that of the output and in fiber Raman amplifier. It is dependent upon the pumping power and the gain of the optical system as [11]:

$$NF \approx \frac{2 g_0}{A_{eff}} \int_0^L \frac{P_P\, dL}{G_A(L)} + \frac{1}{G_{net}(L)} \qquad (8)$$

where $G_A(L)$ is the net gain at distance L along the fiber cable length, A_{eff} is the effective area of the fiber cable core, and $G_{net}(L)$ is the net gain at the end of the fiber cable length. The maximum allowed transmit power per channel (P_T), as a function of fiber cable link length can be expressed as follows [12]:

$$P_T \approx \frac{4\times 10^4}{N_{ch}(N_{ch}-1)\Delta\lambda_S\, L} \qquad (9)$$

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. This is because the lowest wavelength channel, which is also the worst affected channel, now interacts with more number of channels through the process of SRS. Thus, SRS is not a serious effect for small number of channels, but can be serious for higher number of channels. To reduce the effect of SRS for higher number of channels, the spacing is thus reduced. If the spacing is fixed, the power launched decreases with N_{ch} inversely with a square term [13]. The standard single mode fiber cable is made of the pure silica material which the investigation of the spectral variations of the waveguide refractive-index requires empirical equation under the form [14]:

$$n = \sqrt{1 + \frac{A\lambda^2}{\lambda^2 - B^2} + \frac{C\lambda^2}{\lambda^2 - D^2} + \frac{E\lambda^2}{\lambda^2 - F^2}} \qquad (10)$$

The parameters of empirical equation coefficients for silica material as a function of ambient temperature (T) and room temperature (T_0) are as in [14]. Differentiation of first and second order of empirical equation *w.r.t.*λ yield as in [15]. The total bandwidth is based on the total chromatic dispersion (D_t=D_m+D_w) where:

$$D_t = -\frac{\lambda}{c}\left(\frac{d^2 n}{d\lambda^2}\right) - \left(\frac{n_2}{c\, n}\right)\left(\frac{\Delta n}{\lambda}\right) Y \qquad (11)$$

where λ is the operating signal wavelength, c is the velocity of the light, 3×10^8 m/sec, n is the refractive-index of the fiber cable core, n_2 is the refractive-index of cladding material, Y is a function of wavelength, and Δn is the relative refractive-index difference. Assuming the receiver is at the room temperature, and feeds a matched preamplifier with noise figure (NF) in dB, then for a transmitted power P_T in Watts, the optical signal to noise ratio at the receiver ($OSNR$) is [15]:

$$OSNR = \frac{P_T\, L}{NF\, k\, T\, \alpha_S} \qquad (12)$$

where k is the Boltzmann's constant (1.38x10^{-23} J/K), α is the total attenuation coefficient in dB/km, and L is the fiber link length in km. The total pulse broadening $\Delta\tau$ due to total dispersion coefficient can be determined by:

$$\Delta\tau = D_t\, \Delta\lambda_S\, L \quad \text{[nsec]} \tag{13}$$

The allowable signal bandwidth in standard single mode fiber can be expressed as [16]:

$$B.W_{sig.} = \frac{0.44}{\Delta\tau\, L} \quad \text{[GHz]} \tag{14}$$

As well as the Shannon transmission bit rate can be expressed as the following formula:

$$B_{Sh} = 3.3219\, B.W_{sig.}\, \log_{10}\left(1 + OSNR\right) \quad \text{[Gbit/sec]} \tag{15}$$

Moreover the Shannon bit rate-distance product can be expressed as a function of Shannon transmission bit rate and fiber link length as the following expression:

$$P_{Sh} = B_{Sh}\, .\, L \quad \text{[Gbit.km/sec]} \tag{16}$$

The *BER* essentially specifies the average probability of incorrect bit identification. In general, the higher the received *SNR*, the lower the *BER* probability will be. For most PIN receivers, the noise is generally thermally limited, which independent of signal current. The *BER* is related to the *OSNR* as follows [16]:

$$BER = 0.5\left[1 - erf\left(\frac{\sqrt{OSNR}}{2\sqrt{2}}\right)\right] \tag{17}$$

where *erf* is the error function, and *OSNR* is the signal to noise ratio in absolute value.

IV. SIMULATION RESULTS AND DISCUSSIONS

In the analysis of our results, we have investigated the new trends of fiber Raman amplification in DWDM photonic communication networks under the set of affecting operating parameters are shown in Table 1.

Table 1. Suggested operating parameters in DWDM photonic networks

Operating Parameter	Symbol	Value
Operating signal wavelength	λ_S	1.45-1.65 µm
Ambient temperature	T	300-340 K
Room temperature	T_0	300 K
Channel spacing	$\Delta\lambda_S$	0.1-0.8 nm
Pumping wavelength	λ_P	1.4-1.55 µm
Signal attenuation	α_S	0.2-0.5 dB/km
Pump attenuation	α_p	0.35 dB/km
Pumping power	P_P	0.25-0.5 Watt/pump
Transmitted signal power	$P_S=P_T$	2-20 mWatt
Effective area	A_{eff}	85 µm^2
Raman gain coefficient	g_0	0.7 Watt^{-1}.km^{-1}
Relative refractive-index difference	Δn	0.003-0.009
Fiber link length	L	100-1000 km
Number of transmitted channels	N_{ch}	100-1000 channel
On-Off Raman gain	G_A	5-50 dB
Noise figure	NF	2-5 dB

Based on the set of Figures 2-19, the following facts and obtained features are assured as follows:

i) Figures 2 and 3 have assured that as fiber link length increases, these results in decreasing in pumping power that leads to increase in signal power.

ii) Figure 4 has demonstrated that as the fiber link length increases, this leads to increase in noise figure. As well as at signal/pump attenuation equal presents higher noise figure than signal/pump attenuation varying.

iii) Figure 5 has proved that as on-off Raman gain increases, this leads to decrease in noise figure at constant fiber link length. Moreover as fiber link length increases, this results in increasing in noise figure.

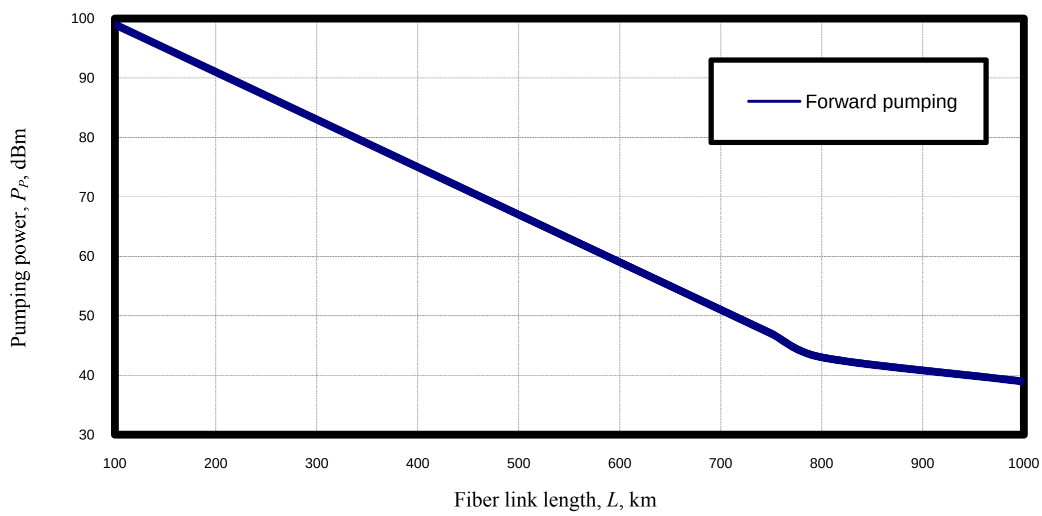

Figure 2. Variations of the pumping power against the fiber link length at the assumed set of parameters

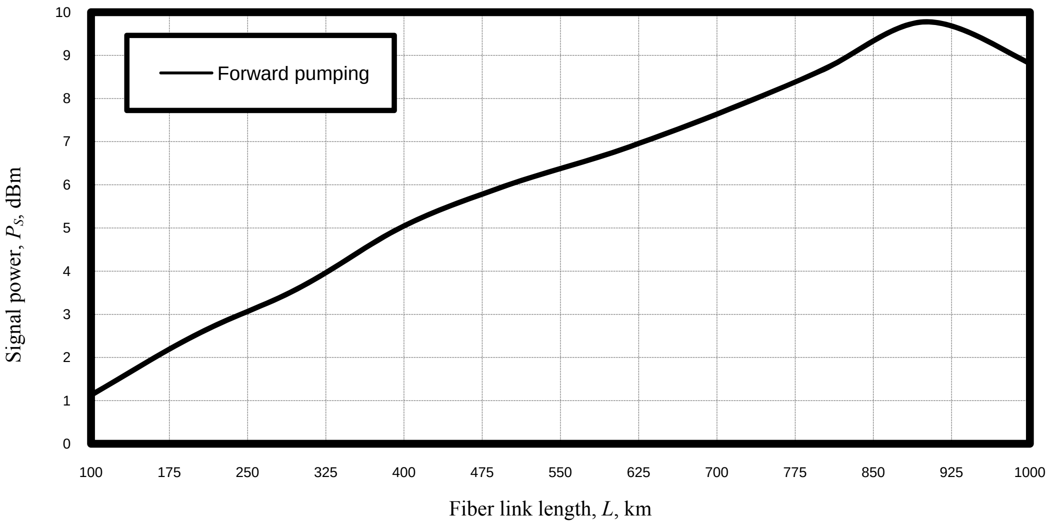

Figure 3. Variations of the signal power against the fiber link length at the assumed set of parameters

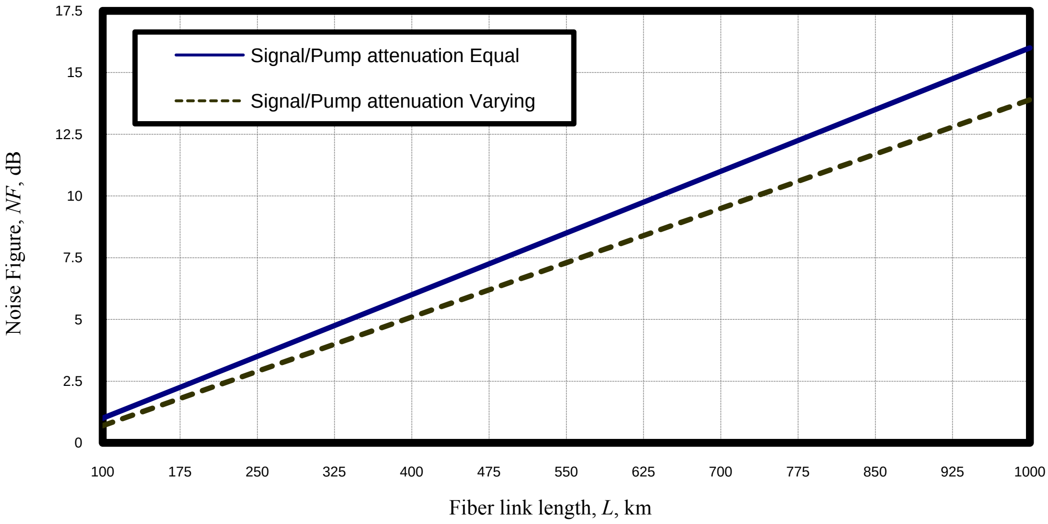

Figure 4. Variations of noise figure against the fiber link length at the assumed set of parameters

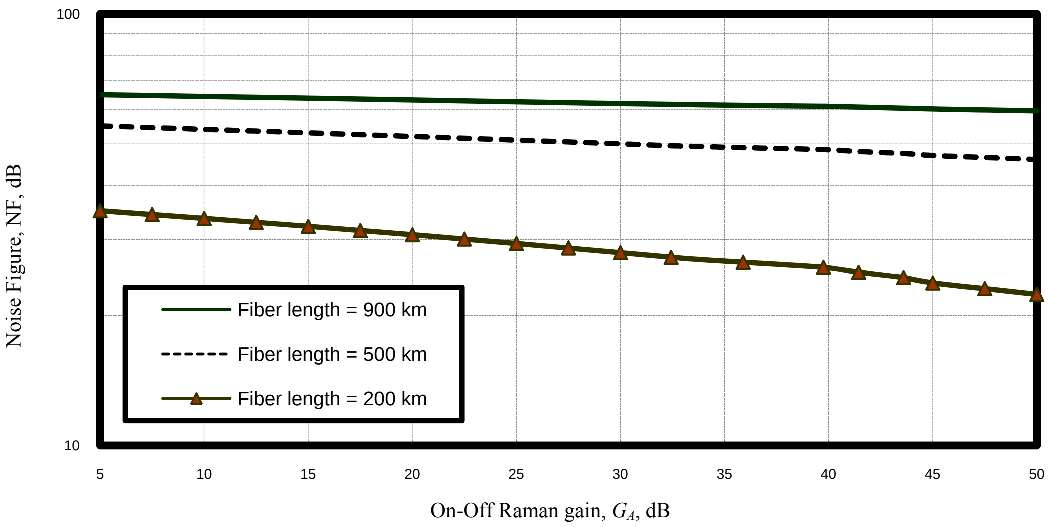

Figure 5. Variations of the noise figure with the on-off Raman gain at the assumed set of parameters

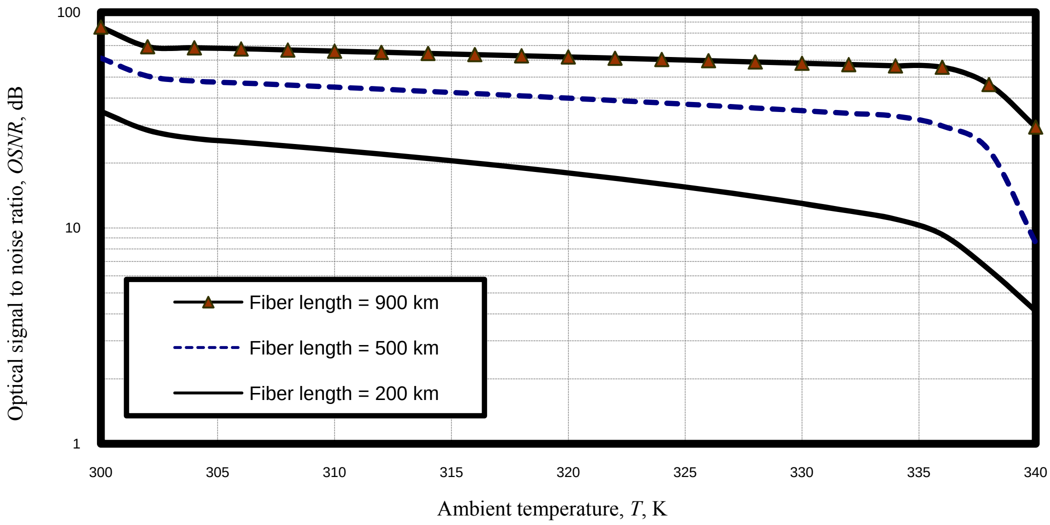

Figure 6. Variations of the optical signal to noise ratio versus ambient temperature at the assumed set of parameters

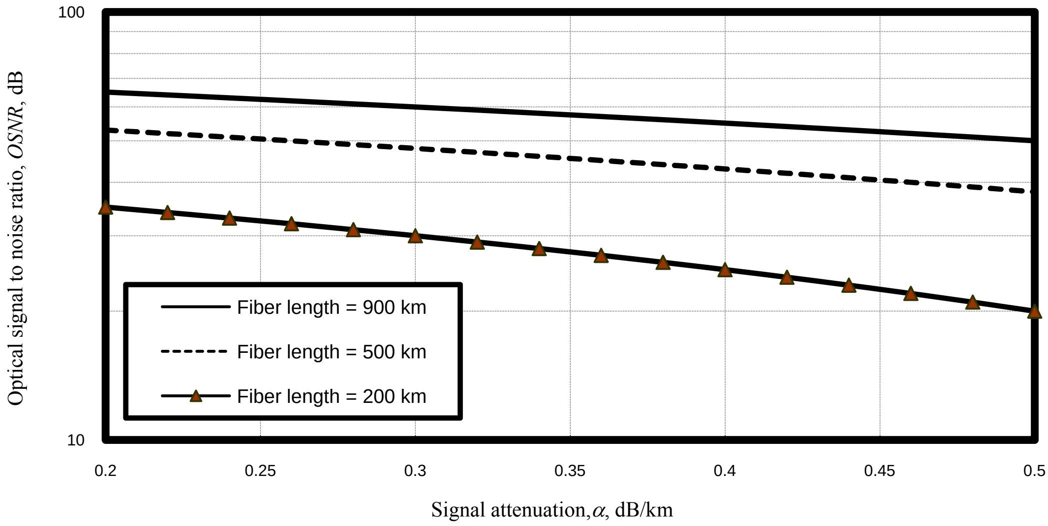

Figure 7. Variations of the optical signal to noise ratio versus signal attenuation at the assumed set of parameters

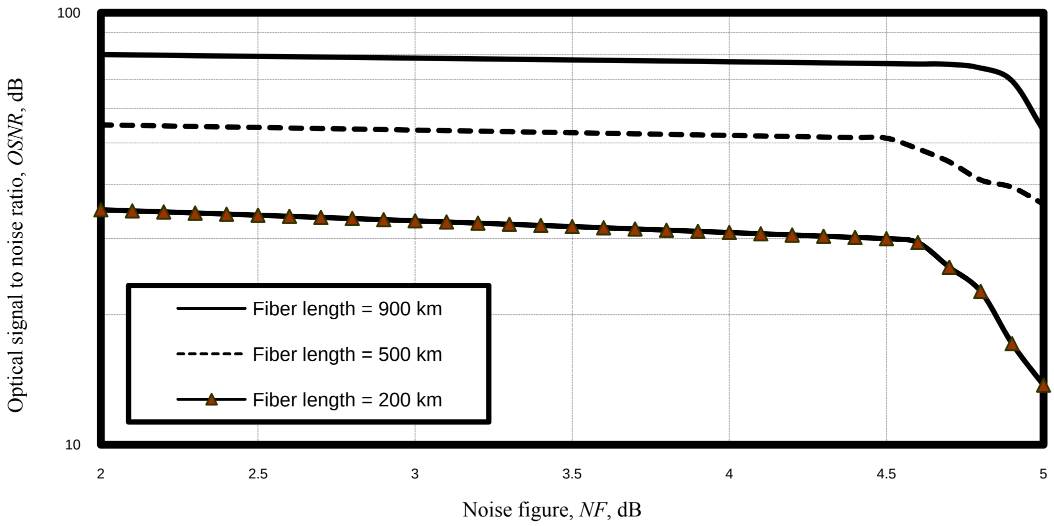

Figure 8. Variations of the optical signal to noise ratio versus noise figure at the assumed set of parameters

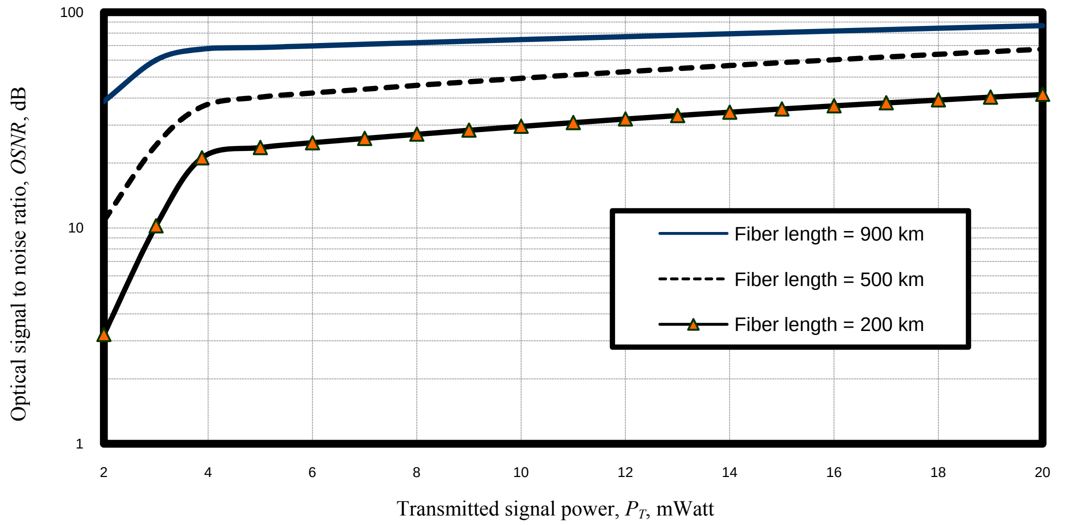

Figure 9. Variations of the optical signal to noise ratio against transmitted signal power at the assumed set of parameters

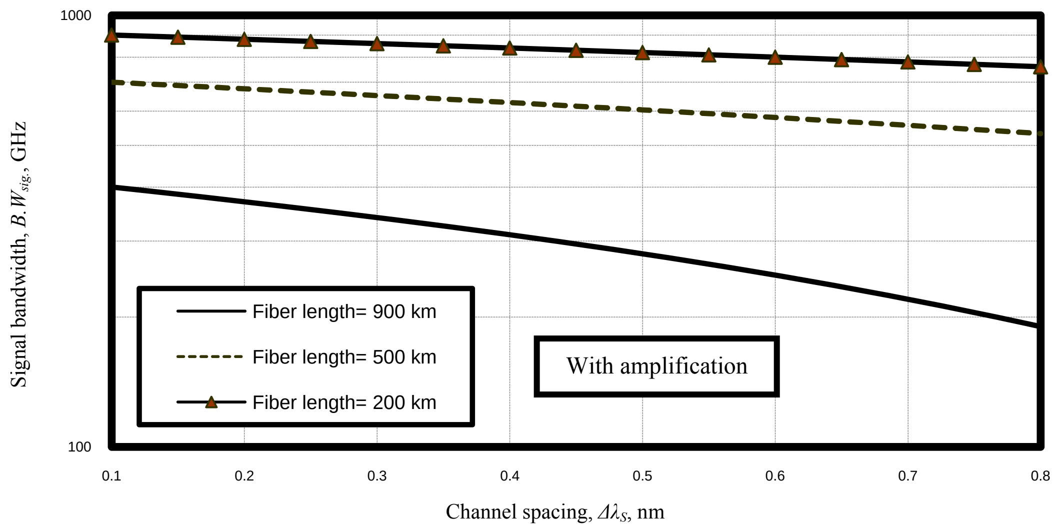

Figure 10. Variations of the signal bandwidth against channel spacing at the assumed set of parameters

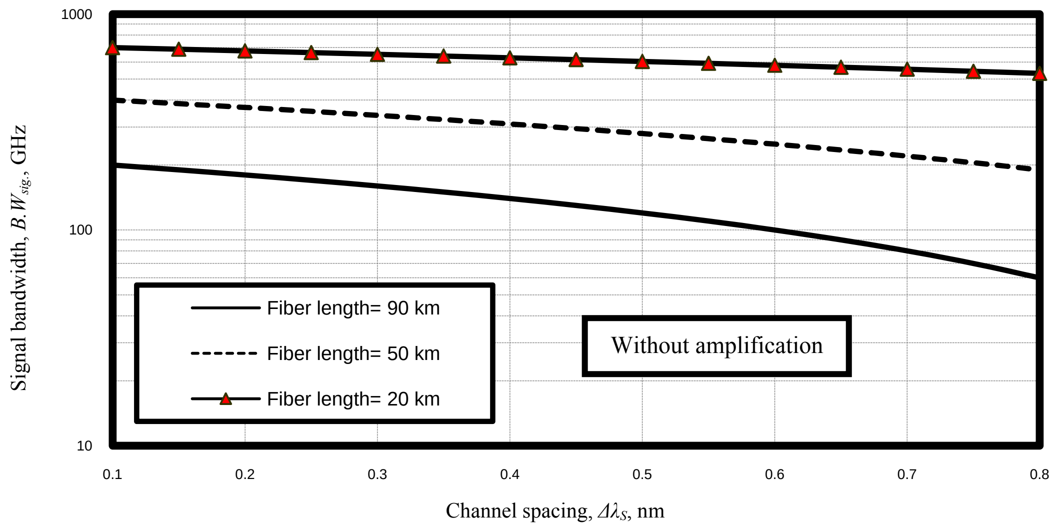

Figure 11. Variations of the signal bandwidth against channel spacing at the assumed set of parameters

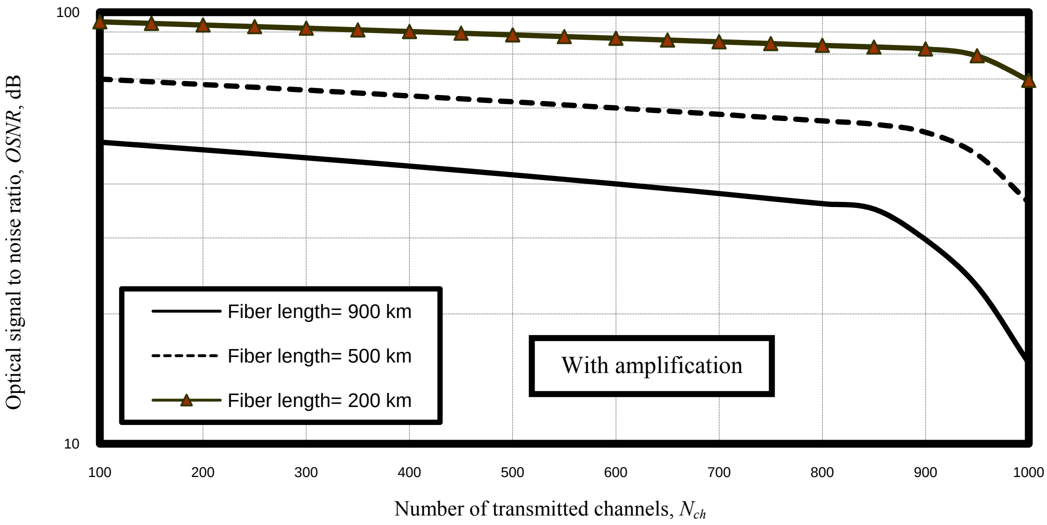

Figure 12. Variations of optical signal to noise ratio against number of transmitted channels at the assumed set of parameters

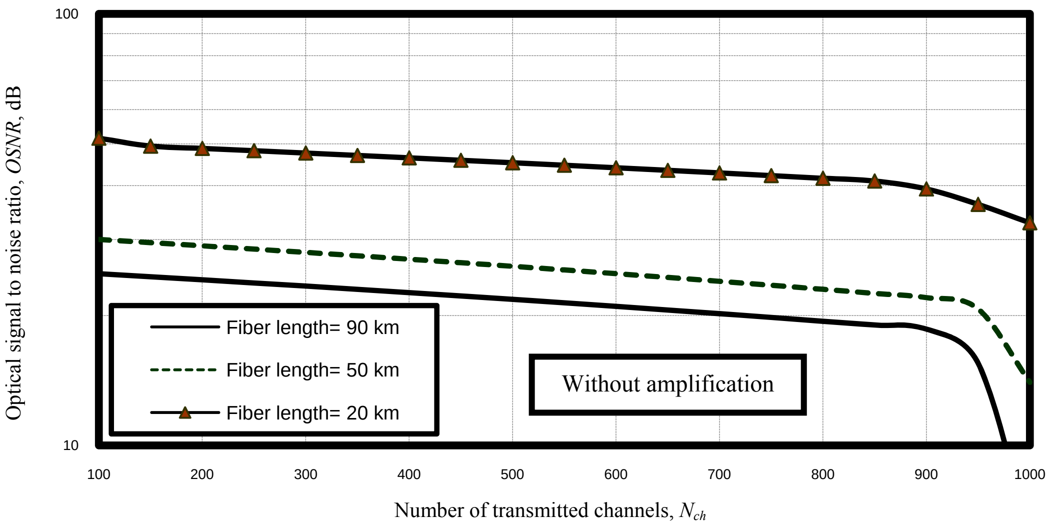

Figure 13. Variations of optical signal to noise ratio against number of transmitted channels at the assumed set of parameters

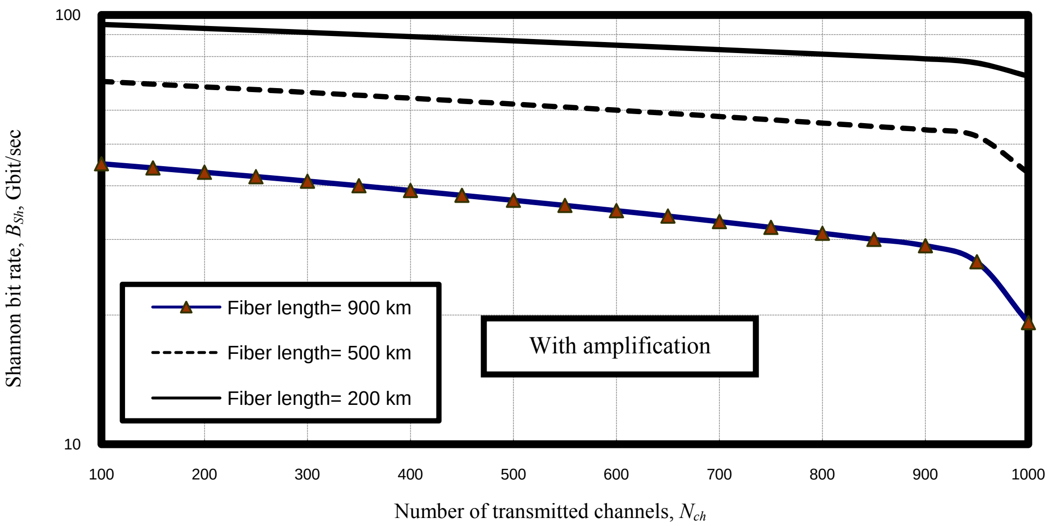

Figure 14. Variations of Shannon bit rate against number of transmitted channels at the assumed set of parameters

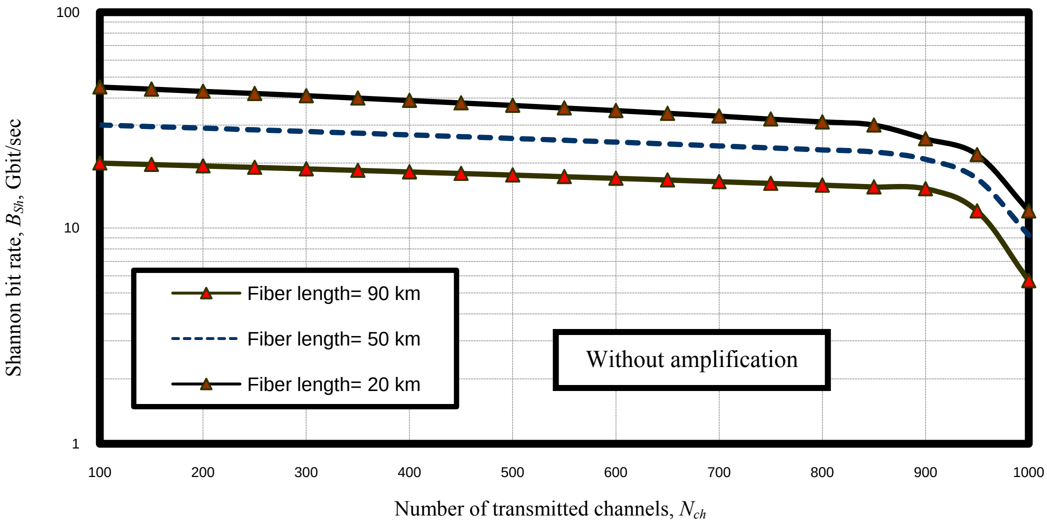

Figure 15. Variations of Shannon bit rate against number of transmitted channels at the assumed set of parameters

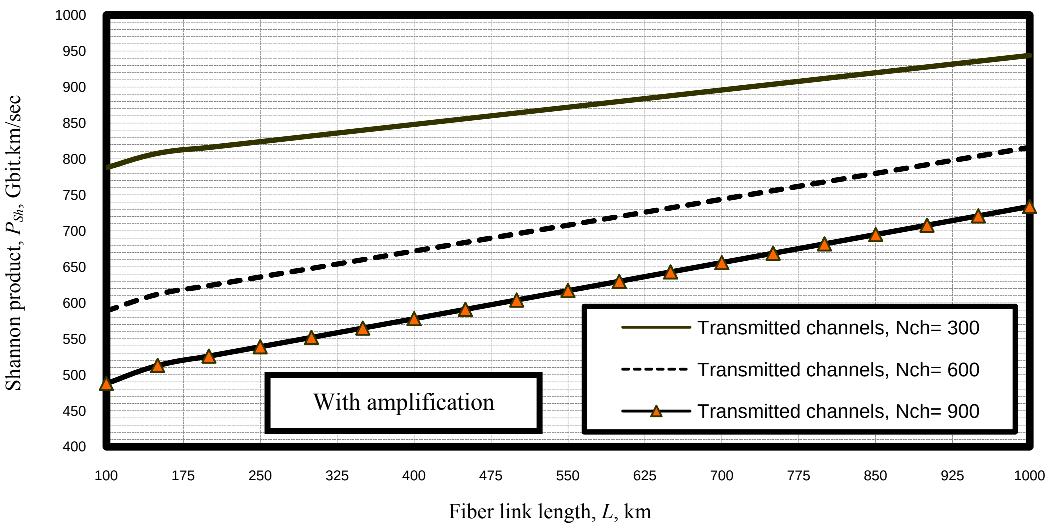

Figure 16. Variations of Shannon bit rate-distance product versus fiber link length at the assumed set of parameters

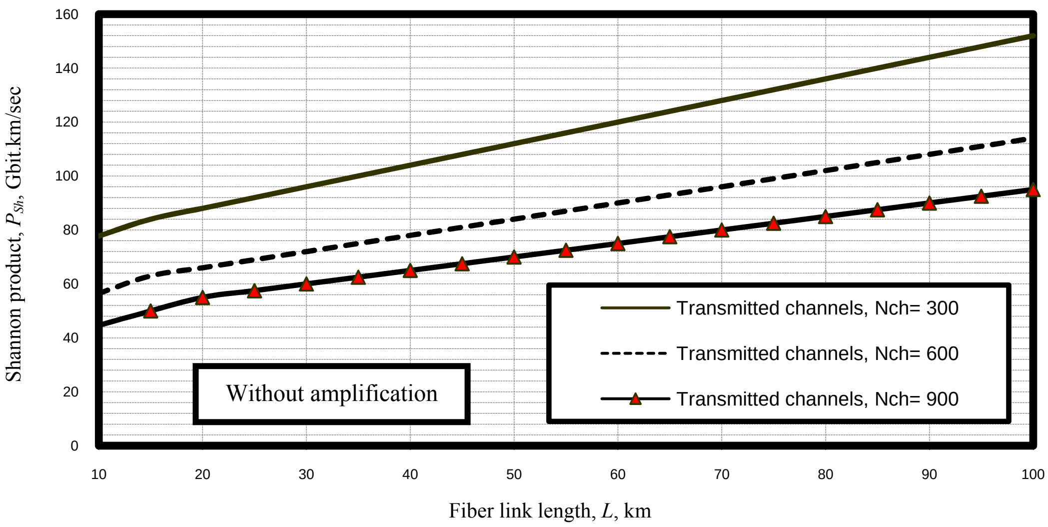

Figure 17. Variations of Shannon bit rate-distance product versus fiber link length at the assumed set of parameters

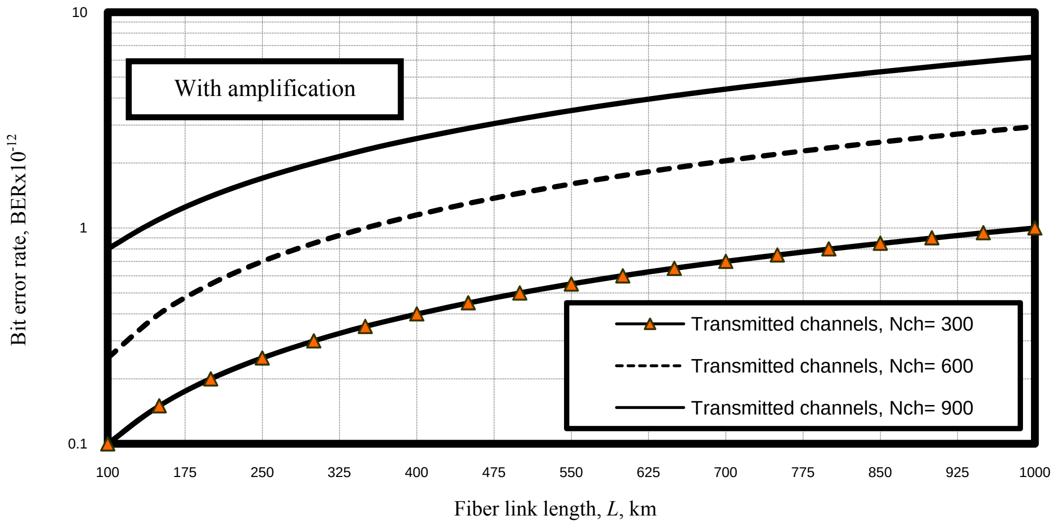

Figure 18. Variations of received bit error rate against fiber link length at the assumed set of parameters

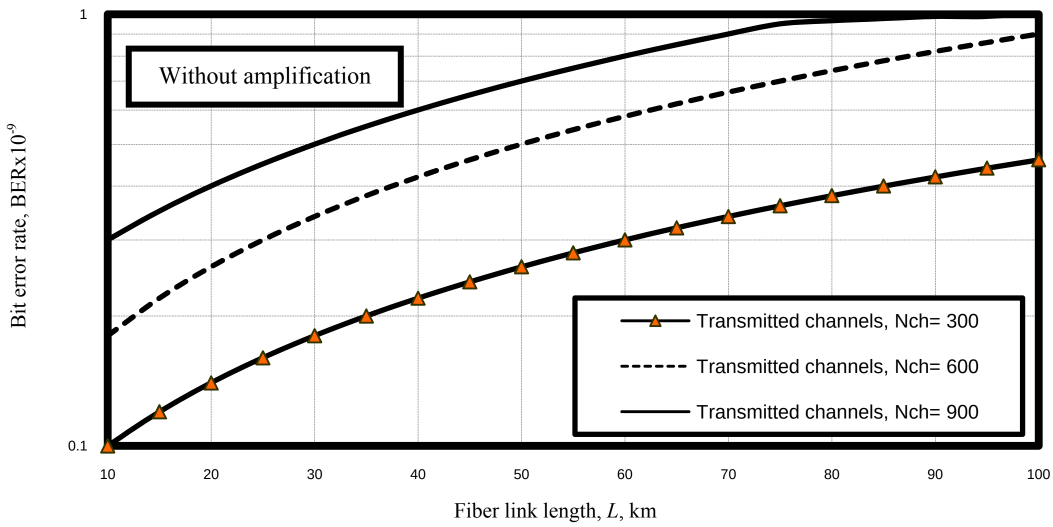

Figure 19. Variations of received bit error rate against fiber link length at the assumed set of parameters

iv) In the series of Figures 6-9 have indicated that as ambient temperature, signal attenuation, and noise figure increase, this result in decreasing optical signal to noise ratio at constant fiber link length. But as both fiber link length and transmitted signal power increase, this leads to increase in optical signal to noise ratio.

v) As shown in Figures 10 and 11 have assured that as channel spacing increases, these results in decreasing in signal bandwidth at constant fiber link length. With forward Raman amplification technique presents both higher fiber link length and signal bandwidth than without amplification case.

vi) As shown in Figures 12-15 have demonstrated that as number of transmitted channels increases, this result in decreasing in both optical signal to noise ratio and Shannon bit rate at constant fiber link length. With forward Raman amplification technique presents higher fiber link length, optical signal to noise ratio, and Shannon bit rate than without amplification case.

vii) As shown in Figures 16-19 have assured that as fiber link length increases, these results in increasing in both Shannon bit rate-distance product and bit error rate at constant number of transmitted channels. With forward Raman amplification technique presents higher Shannon bit rate-distance product than and lower bit error rate without amplification case.

V. CONCLUSIONS

In a summary, we have been investigated and modeled forward Raman gain amplification technique for DWDM photonic networks over wide range of the affecting parameters. It is observed that the increased fiber link length, the increased of both signal power and noise figure, and the decreased pumping power. As well as the increased on-off Raman gain, the decreased noise figure. Moreover, the decreased ambient temperature, signal attenuation, and noise figure, the increased optical signal to noise ratio (OSNR). The increased of both transmitted signal power, and fiber link length, the increased OSNR. With forward Raman amplification presents higher fiber link length, signal bandwidth, Shannon bit rate, OSNR, Shannon bit rate-distance product and the lower bit error rate (BER) without amplification case.

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BIOGRAPHY

Ahmed Nabih Zaki Rashed was born in Menouf, Menoufia State, Egypt on July 23, 1976. He received the B.Sc., M.Sc., and Ph.D. scientific degrees from the Electronics and Electrical Communications Engineering Department, Faculty of Electronic Engineering, Menoufia University (Menouf, Egypt) in 1999, 2005, and 2010 respectively. Currently, his job carrier is a scientific lecturer in Electronics and Electrical Communications Engineering Department, Faculty of Electronic Engineering, Menoufia University. His scientific Ph.D. thesis has focused on recent applications in linear or nonlinear passive or active in optical networks. His interesting research mainly focuses on transmission capacity, a data rate product and long transmission distances of passive and active optical communication networks, wireless communication, radio over fiber communication systems, and optical network security and management. He has published many high scientific research papers in high quality and technical international journals in the field of advanced communication systems, optoelectronic devices, and passive optical access communication networks. His areas of interest and experience in advanced optical communication systems, advanced optical communication networks, wireless optical access networks, digital communication systems, optoelectronics devices, network security, encryption and optical access computing systems. He is a reviewer member in high quality scientific research international journals in the field of Electronics, Electrical communication and advanced optical communication systems and networks.