International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 3, Issue 1, January 2014

Unwanted Effects on the Transmission Characteristics of Radio over Fiber (ROF) in the Optical Communication Networks

Osama A. Oraby
Electronics and Electrical Communications Engineering Department
Faculty of Electronic Engineering, Menouf 32951, Menoufia University, EGYPT
E-mail:osamaorabi75@yahoo.com

Abstract- This paper has presented the different data transmission limitations in radio over fiber communication systems such as total losses and fiber dispersion. These limitations can be solved by Soliton transmission technique. Signal to noise ratio, bit error rate, and optical signal to noise ratio can be investigated. The transmission bit rate per channel can be analyzed with using both space division, dense wavelength division multiplexing techniques and Soliton propagation technique.

Index Terms- Signal to noise ratio, Bit error rate, Space division multiplexing, ROF, Fiber loss, and Fiber dispersion.

I. INTRODUCTION

Fiber-optic cable has a low loss, a large bandwidth and is cheap compared to coaxial cable, so transportation of microwaves by using fiber-optic cables is very attractive. Transporting microwaves over optical fiber is called in general Radio over Fiber. A way to transport a microwave signal is by modulating it onto an optic carrier by using a laser, and transport it over fiber-optic cable and convert it back to a microwave electrical signal by intensity detection in a photodiode. This is called intensity modulation - direct detection (IMDD) [2]. A drawback of this configuration is that a microwave source is needed at the frequency of the generated microwave signal and that a laser must be used that is capable of modulating the light by the microwave signal. A different way to (virtually) transport a microwave signal is to generate two optical carriers separated by a frequency equal to the microwave signal to be generated. In the photodetector at the receiving end, the two optical carriers are mixed and the relevant part of mixing products at the output of the photodetector consists of a signal with a frequency equal to the frequency separation of the optical carriers. This is called remote heterodyning detection (RHD) [2]. Some other procedures to use fiber optic cable to transport microwaves are investigated by researchers around the world [3].

Since the RHD method is a coherence method, the lasers used must be highly coherent and the link must retain this coherency. Single mode silica fibers can retain the coherency since only one transverse mode is traveling in the fiber. Single mode silica fibers have a small core, are very delicate and special equipment is needed to handle such fibers. They are extensively used in high-performance long-reach core and metropolitan networks. The use of polymer optical fiber, that is a multimode fiber, is preferred because of its large core, flexibility and its ease to handle. Guiding light in multiple modes, as done in multimode (silica or polymer) optical fibres, destructs the phase coherence needed for RHD, and the pertaining modal dispersion strongly limits the fiber's bandwidth and thus the microwave IM-DD potential. The use of a multimode fiber requires therefore a system where the retainment of the coherency in the link is not important [4, 5].

II. MODELING BASICS AND ANALYSIS

The performance of ROF systems, as well as in traditional optical communications networks, can be affected by linear and nonlinear impairments. Particularly, in ROF systems, the fiber chromatic dispersion can degrade the transmitted Radio Frequency (RF) signal by means of fading effects. The fading effect can lead to cosine like fluctuation of the signal power along the fiber, which means that the signals periodically vanishes at specific pairs of frequencies and fiber lengths. This phenomenon is similar to multipath effect in wireless systems and happens because sidebands around the optical carrier, arising from modulation process, travel into the optical fiber with different group velocities [1].

II.1. ROF DISPERSION MODEL

First order dispersion changes phase of each sideband relative to the carrier [2] as:

$$\varphi = \frac{1000\pi L_f \; D_t(\lambda)\lambda_c^2 \, f_{RF}^2}{c}, \tag{1}$$

Where L_f is the fiber link length, φ is first order dispersion, λ_c is the central wavelength, f_{RF} is the RF frequency, c is the light speed (is equal to 3 $\times 10^8$ m/sec) and D_t is the total dispersion coefficient as a function of operating wavelength in the fiber media is given by the following expression as the following [3].

$$D_t(\lambda) = -\frac{\lambda_s}{c}\frac{dn}{d\lambda} - \frac{\Delta\lambda}{2c}\left(\frac{d^2n}{d\lambda^2}\right) - n_2\left(\frac{\Delta n}{c\,\lambda_s}\right)F(V), \tag{2}$$

Where n_2 is the refractive-index of the cladding material, Δn is the relative refractive-index difference, λ_s is the operating signal wavelength, F (V) is a function of V number (normalized frequency). Based on the work [3], they designed the function F (V), with employing V number in the range of ($0 \le V \le 1.15$) yields:

$$F(V) = 1.38V - 6.98V^2 + 13.45V^3, \tag{3}$$

In our simulation model design, we are taking into account V-number as unity to emphasis single mode operation [3]. Based on Ref. [4], the refractive index of pure silica waveguide as optical fiber media is cast under the Sellemier equation. The parameters is adjusted as: A= 0.691663, B= $(0.068404)^2$ $(T/T_0)^2$, C= 0.407942, D=$(0.1162414)^2$ $(T/T_0)^2$, E=0.8974749, and F= $(9.896161)^2$. Where T is ambient temperature in K, T_0 is the room temperature and is considered 300 K. Then the first and second differentiation of Sellemier equation with respect to operating wavelength λ as in the series of equations in [5].

II. 2. ROF ATTENUATION MODEL

Based on the models of Ref. [6], the silica-doped spectral losses are cast as:

$$\alpha = \alpha_I + \alpha_S + \alpha_{UV} + \alpha_{IR}, \quad \text{dB/km} \tag{4}$$

Where: $\alpha_I \equiv the\ \mathrm{int}\,rinsic\ loss \cong 0.03$, dB/km, and (5)

$$\alpha_S \equiv Rayleighscattering = \left(\frac{0.75+66\Delta}{\lambda^4}\right)\left(\frac{T}{T_0}\right) \quad , \text{ km} \tag{6}$$

Where T is ambient temperature, and T_0 is a room temperature (300 K), Δ and λ are the relative refractive index difference and optical wavelength respectively. The absorption losses α_{UV} and α_{IR} are given as [6]:

$$\alpha_{UV} = 1.1\times10^{-4}\,\omega_{ge}\%\; e^{4.9\lambda}, \qquad \text{dB/km} \tag{7}$$

$$\alpha_{IR} = \left(7\times10^{-5}\; e^{-24/\lambda}\right)^2, \qquad \text{dB/km} \tag{8}$$

Where ω_{ge} % is the weight percentage of Ge, the correlated ω_{ge} % and the mole fraction x under the form:

$$\omega_{ge}\% = 213.27x - 594x^2 + 2400x^3 - 4695x^4 \tag{9}$$

Plastics, as all any organic materials, absorb light in the ultraviolet spectrum region. The absorption depends on the electronic transitions between energy levels in molecular bonds of the material. Generally the electronic transition absorption peaks appear at wavelengths in the ultraviolet region [7]. According to urbach's rule, the attenuation coefficient α_e due to electronic transitions in plastic optical fiber. In addition, there is another type of intrinsic loss, caused by fluctuations in the density, orientation, and composition of the material, which is known as Rayleigh scattering.. This phenomenon gives the rise to scattering coefficient α_R that is inversely proportional to the fourth power of the wavelength, i.e., the shorter is λ the higher the losses are. For a plastic fiber, it is shown that α_R is given [8], then the total losses of plastic material is given by:

$$\alpha = 1.10\times10^{-5}\exp\left(\frac{8}{\lambda}\right) + 13\left(\frac{0.633}{\lambda}\right)^4, \text{ dB/km} \tag{10}$$

Almost all ROF links use single mode fiber. Hence the fiber dispersion is not an issue with ROF links up to several tens of kilometers when the RF frequencies are less than 10 GHz. Fiber attenuation is a function of wavelength. Modern fibers offer as low as 0.2 dB/km loss at 1.55 µm. Connectors and splices will add few more dB loss. The optical losses together can be named as OL including fiber attenuation and connector losses. In a point-to-point fiber link can be [9, 10]:

$$OL = 2\left(N\,L_c + M\,L_{sp} + \alpha L_f\right), \; dB \tag{11}$$

Where NL_c is the connector loss with N connectors; ML_{sp} is the splicing loss with M splices, and α is the fiber attenuation in dB/km. The OL could, however, be very large with passive optical networks (PON) despite their attractiveness [9, 10]. The power is lost every time the power is split can be computed as follows:

$$OL = 2\left(N\,L_c + M\,L_{sp} + S\,L_{split} + \alpha L_f\right), \; dB \tag{12}$$

Where there are S splitters each with loss L_{split}. The total loss due to the ROF link with resistive matching at the O/E and E/O converters can be shown as the following equation [11]:

$$L_{op} = 20\log\left(G_m\,R/0.001\right) + 10\log\left(Z_{out}/Z_{in}\right) + 2OL \quad , \tag{13}$$

Where OL is the optical losses including fiber attenuation and connector losses. The second term is zero when the input to the laser and the output of the optical receiver are matched to the same RF impedance ($Z_{out} = Z_{in} = 50\ \Omega$) with $G_m = 0.12$ mW/mA [11].

II. 3. OPTICAL SIGNAL TO NOISE RATIO

In the shot noise limited case, the optical signal to noise ratio of ROF link can be expressed as [11]:

$$OSNR = \frac{m^2 I_D\, E\left[s^2(t)\right] 10^{-\alpha_{op}/10}}{2q\ B} \quad , \tag{14}$$

That is the OSNR increases with mean detected current I_D linearly and with m in second order. Mean detected current is proportional to mean optical power P_0. However, note that typically larger P_0 means lower m again due to nonlinear effects. Nevertheless, the OSNR eventually would increase with m. In the RIN limited case, Eq. (14) can be deduced as in Ref. [12]. That is the OSNR is independent of mean optical power and increases with RF power. However, when the RF power is too large the OSNR would saturate due to large RIN as observed by [12]. The signal to noise ratio (SNR) can be expressed as a function of OSNR as [11, 12]:

$$SNR = OSNR\left[\frac{1}{1+\left(\dfrac{\alpha_{wired}}{G_{op}}\right)^2}\right]. \tag{15}$$

Let us consider a general fiber link area in which the maximum power loss is specified as α in dB. α depends on the fiber link area and radio environment. At the maximum loss point in the fiber link, $\alpha_{worst} = 10^{\alpha/10}$. Hence, the worst case SNR is given as in Ref. [12], and then the required optical receiver amplifier gain for different values of the maximum loss α in the fiber link area given the value for OSNR and worst case SNR at the portable and then the maximum loss, α and minimum required OSNR are also given in Ref. [12]. To evaluate the performance of an optical link, the optical signal to noise ratio (OSNR) is needed. It is evaluated at the output of the optical receiver. The OSNR can be expressed as [13, 14]:

$$OSNR = \frac{\lambda_s\, P_T}{2h\ c\, B.W_{Up=Down}} = \frac{0.5\,P_T}{f_{RF}\ h\, B.W_{Up=Down}} \quad , \tag{16}$$

Where h is the Planck's constant (6.02 x10^{-34} J.sec), c is the speed of light (3x10^8 m/sec), λ_s is the operating optical signal wavelength in mm, f_{RF} is the radio frequency in MHz.

II. 4. BIT ERROR RATE

The bit error rate (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 bit error rate (BER) is related to the signal to noise ratio (SNR) as follows [15]:

$$BER=0.5\left[1-erf\left(0.3535\,(SNR)^{1/2}\right)\right] \quad , \qquad (17)$$

II. 5. SOLITON TRANSMISSION TECHNIQUE

The idea of soliton transmission is to guide the nonlinearity to the desired direction and use it for our benefit. When soliton pulses are used as an information carrier, the effects of dispersion and nonlinearity balance each other and thus don't degrade the signal quality with the propagation distance. In addition, the unique features of soliton transmission can help to solve the problems of data transmission, because the soliton data looks essentially the same at different distances along the transmission, the soliton type of transmission is especially attractive for all-optical data networking. Moreover, because of the high quality of the pulses and return-to-zero (RZ) nature of the data the soliton data is suitable for all-optical processing. 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. In the sense that their sum is an irrelevant constant phase shift. Under such conditions the pulse shape is the same everywhere. All this provided that a soliton waveform be used with a peak power [16, 17]:

$$P_1=\frac{\Delta\lambda^3\,\varphi\,A_{eff}}{4\pi^2 c\, n_{nl}\, t_0^2} \quad , \qquad (18)$$

Where n_{nl} 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 fiber in μm^2, φ is the first order dispersion. Then the total pulse intensity width in psec is:

$$t_0=\sqrt{\frac{\Delta\lambda^3\,\varphi\,A_{eff}}{4\pi^2 P_1\, n_{nl}\, c}} \quad , \quad p\sec \qquad (19)$$

Then the Soliton transmission bit rate per optical network channel or unit is given as follows [18]:

$$B_{rsc}=\frac{1}{10\,t_0}=\frac{0.1}{t_0}, \ Tbit/\sec/channel \qquad (20)$$

In the system model analysis, the transmitted channels per link is given by:

$$N_{ch/Link}=\frac{N_{cht}}{N_L} \quad , \qquad (21)$$

Where N_{Link} is the total number of links in the fiber cable core, and N_{cht} is the total number of channels per fiber cable core. 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:

$$P_{rsc}=B_{rsc}\,.\,L_f, \ Tbit.km/\sec \qquad (22)$$

II. 6. SPACE DIVISION MULTIPLEXING (SDM) TECHNIQUE

We have modeled and investigated parametrically the basic Soliton transmission techniques to transmit 100-600 optical channels based on wavelength division multiplexing (DWDM), in the interval of 1 up to 1.5 mm wavelengths. For the reality from the points of view of the spectral dependences of the different fiber characteristics [19], we employ also the space division multiplexing where 100-600 channels are divided into subgroups each subgroup has its own spectral characteristics. With total number of links, N_L= {4, 5, 6, 7, 8, 9,..24} Links. With JS={1, 2, 3, 4, 5,……...………………..……….N_L}.

Where: $\Delta\lambda_L=\Delta\lambda/N_L \equiv Link\,spacing$ (23)

$$\delta\lambda_s=\Delta\lambda_s/\left(N_{ch}\,.\,N_L\right)=\Delta\lambda_L/N_{cht} \qquad (24)$$

Where N_{ch} is the number of transmitted optical channels per optical link, N_L is the total number of optical links per fiber cable core, and $\Delta\lambda_s=\lambda_f-\lambda_i$ =0.5 mm.

III. PERFORMANCE ANALYSIS

The high performance of ROF communication systems has been investigated for ultra high transmission capacity under the set of the wide range of the operating parameters as listed: 300 K ≤ T, ambient temperature ≤ 340 K, 40 km ≤ L_F, fiber link length ≤ 400 km, $\Delta\tau_{source}$ is the rise time of the transmitter=16 psec, $\Delta\tau_{receiver}$ is the rise time of the receiver=25 psec, 0.0 ≤ x, mole fraction of germanium ≤ 0.3, T_0 is the reference temperature=300 K, RIN is the relative intensity noise=-155 dB/Hz, Δλ is the spectral line width of the optical source=0.1 nm, 1 mm ≤ λ_s, RF operating signal wavelength ≤ 1.5 mm, 0.2 Watt ≤ P_0, mean optical power ≤ 0.597 Watt, Z_{in} is the input impedance of the laser transmitter=50 Ω, Z_{out} is the output RF impedance of the receiver=50 Ω, 0.1 ≤ m, optical modulation index ≤ 0.9, L_C is the connector loss=0.1 dB/km, ρ is the detector responsivity=0.75 mA/mW, G_m is the modulation gain of the laser=0.12 mW/mA, 5 dB ≤ OSNR, optical signal to noise ratio ≤ 25 dB, and F is the amplifier figure noise=5 dB. The following numerical data of the set of assumed affecting parameters of our suggested model are shown in Table 1 have been employed to obtain the transmission performance characteristics of ROF systems in local area optical communication networks (LAOCN) as the following operating parameters. Based on the set of the Figs. (1-13), the following facts are assured as the following results:

i) Figs (1-3) has demonstrated that as fiber link length increases and operating radio frequency this results in increasing optical losses. As well as number of connectors increase this lead to increase in optical loss also. It is indicated that lager plasatic optical fiber losses than silica fibers at different dopant levels.
ii) As shown in Figs. (4-8) have assured that signal to noise ratio increases with increasing both modulation index, optical signal to noise ratio, and optical amplifier gain for different fiber materials fabrication. It is observed that optical signal to noise ratio increases with increasing transmitted signal power and decreasing radio signal frequency.
iii) Figs. (9-12) have indicated that bit error rate decreases with increasing both modulation index, optical signal to noise and optical amplifier gain for different silica and plastic fibers under study considerations.
iv) Fig. 13 has assured that soliton transmission bit rate increases with increasing number of links in the fiber cable core and decreasing total number of channels per link.

Table 1: Proposed operating parameters for our suggested ROF transmission systems [3, 5, 12, 19].

Operating parameter	Definition	Value and units
T	Ambient temperature	300 K $\leq$ T $\leq$ 340 K
Δn	Rrefractive-index difference	0.007
N_L	Number of optical links	$4 \leq N_L \leq 24$
N_{cht}	Number of channels	$100 \leq N_{cht} \leq 600$
f_{RF}	RF operating frequency	$200 \leq f_{RF}$, GHz ≤ 300
λ_s	RF signal operating wavelength	1 mm $\leq \lambda_s \leq$ 1.5 mm
L_f	Fiber link length	2 Km $\leq L_f \leq$ 20 Km
P_0	Optical power	$0.2 \leq P_0$, Watt ≤ 0.597
n_2	Refractive index of cladding	1.445
A_{eff}	Effective area of fiber	85 μm^2
$\Delta\lambda$	Spectral width of optical source	0.1 nm
α at λ=1.55 μm	fiber attenuation	0.2 dB/km
N	Number of connectors	$4 \leq N \leq 32$
L_c	Connector loss	0.3 dB/km

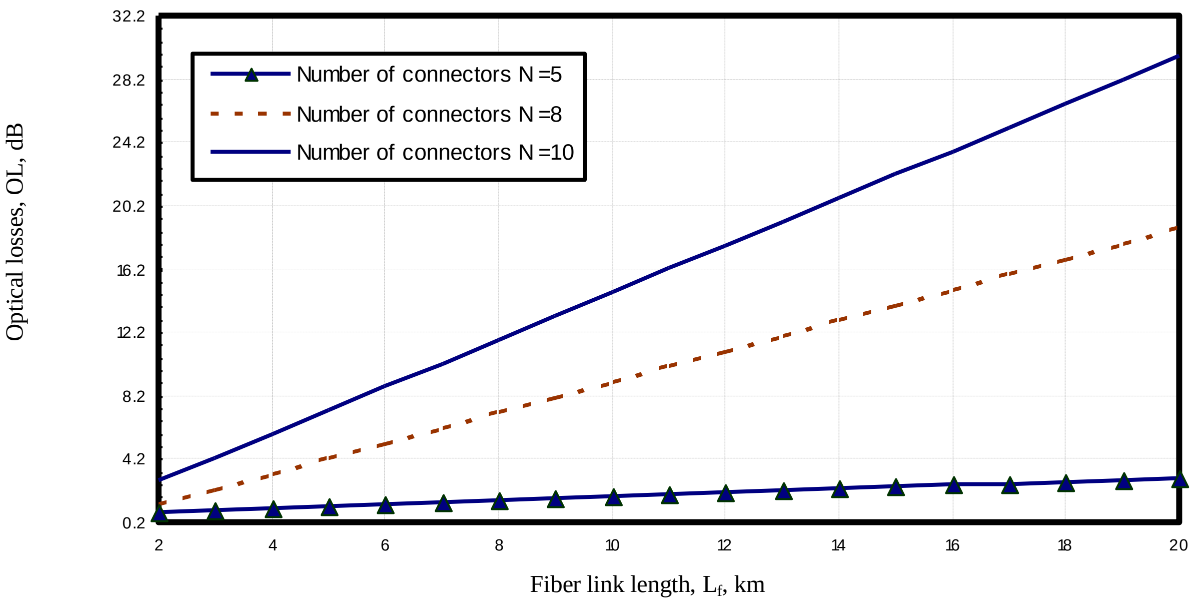

Fig. 1. Variations of optical losses against fiber link length at the assumed set of parameters.

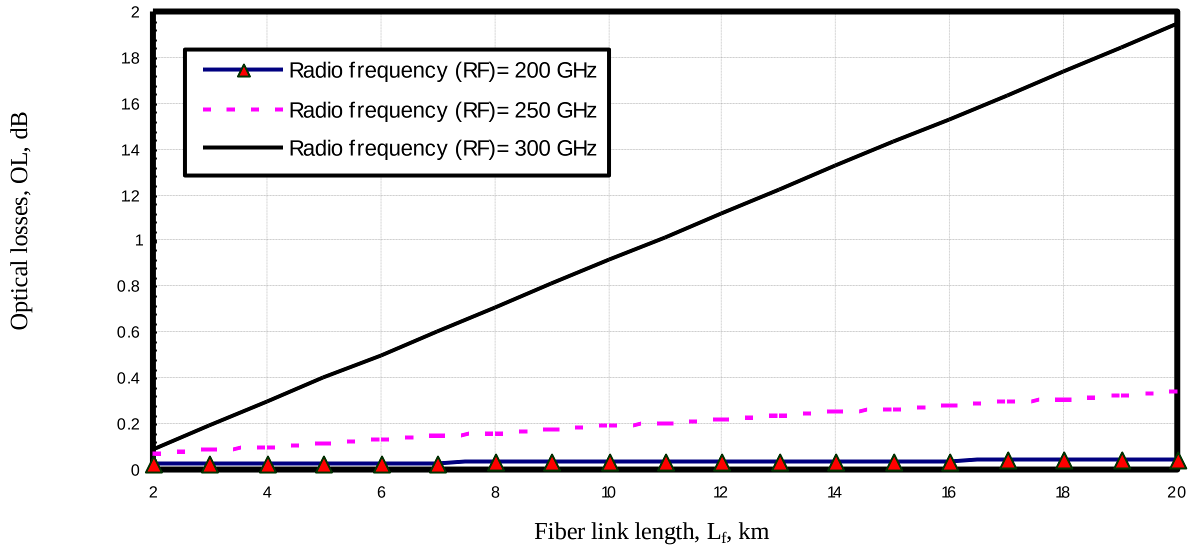

Fig. 2. Variations of optical losses against fiber link length at the assumed set of parameters.

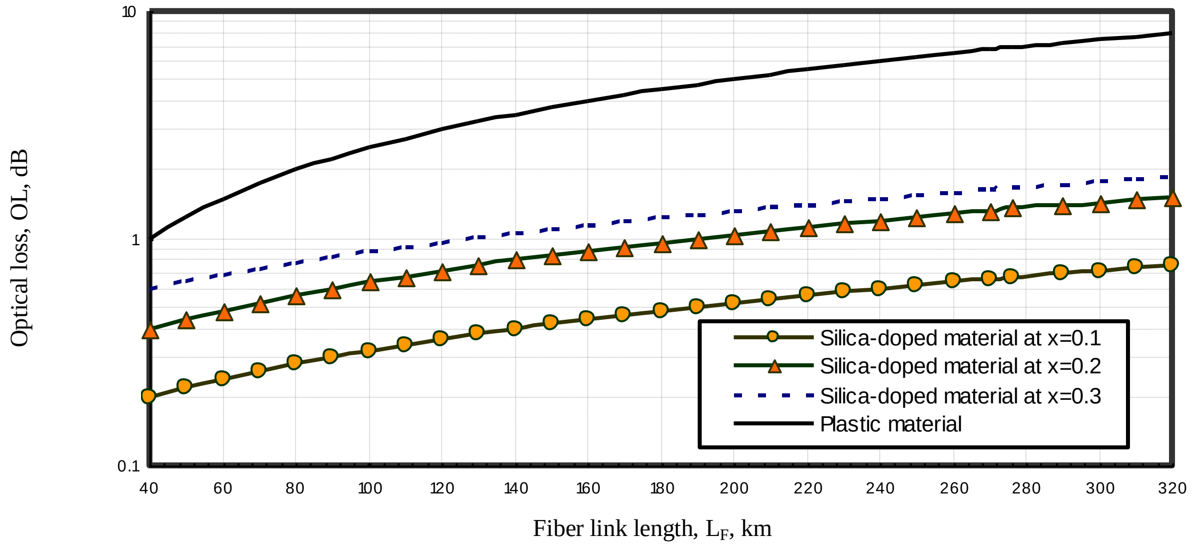

Fig. 3. Variations of the optical loss against fiber link length at the assumed set of parameters.

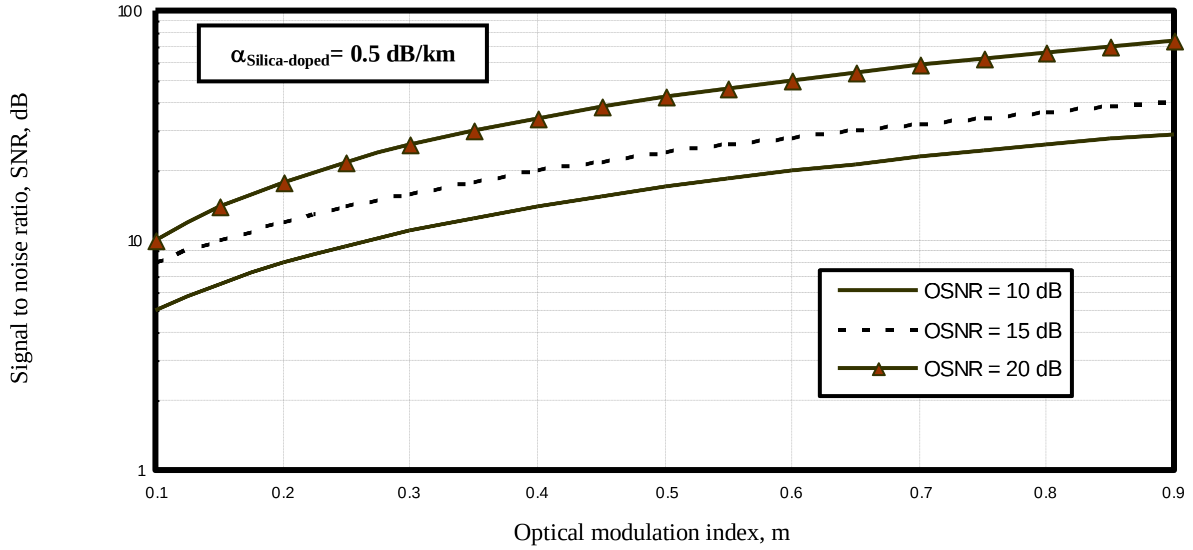

Fig. 4. Variations of signal to noise ratio against optical modulation index at the assumed set of parameters.

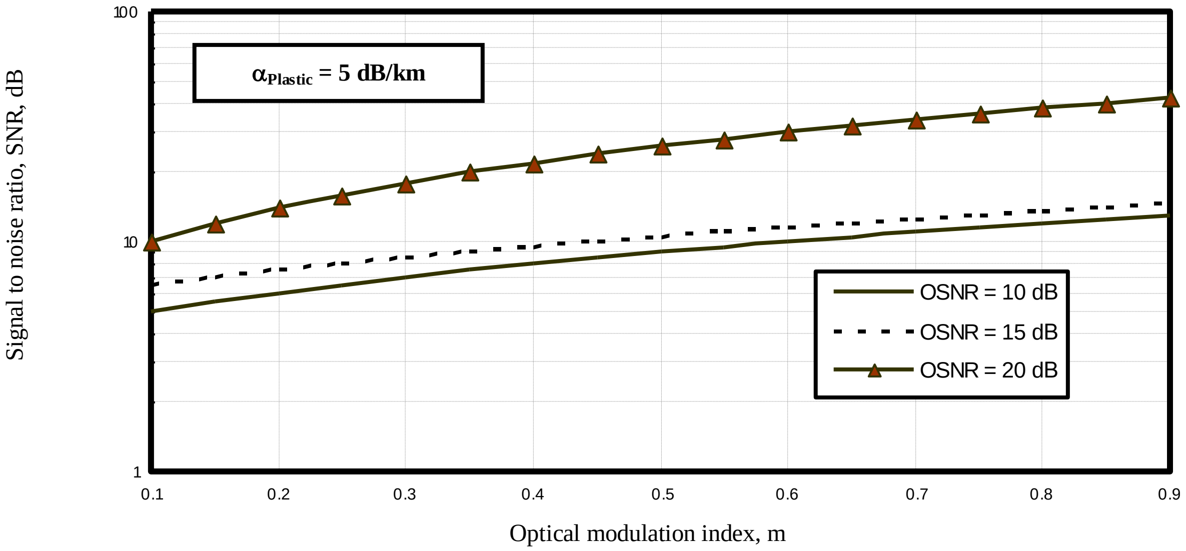

Fig. 5. Variations of signal to noise ratio against optical modulation index at the assumed set of parameters.

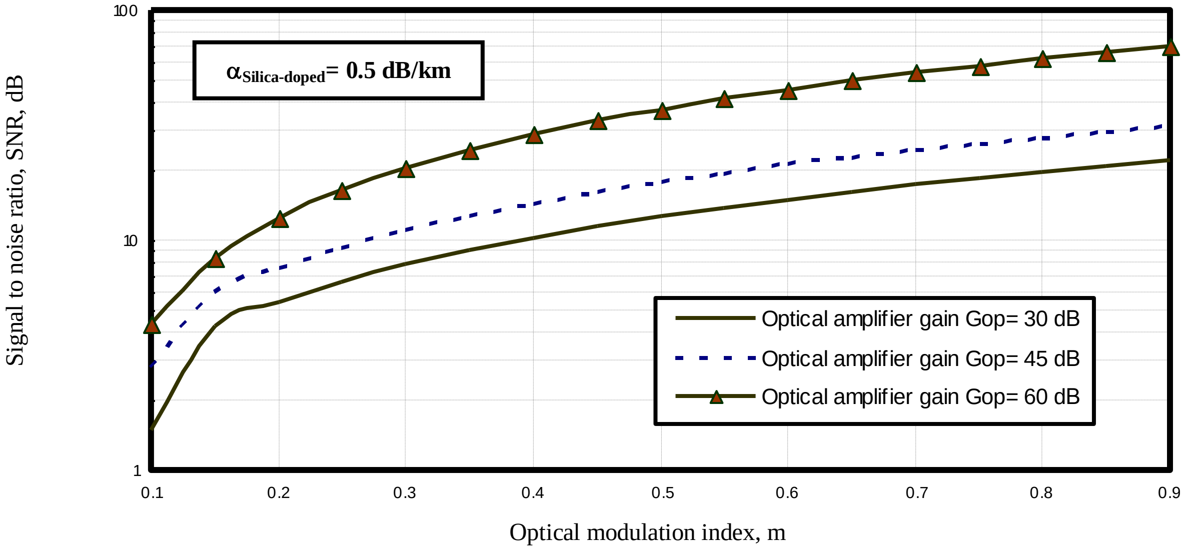

Fig. 6. Variations of signal to noise ratio against optical modulation index at the assumed set of parameters.

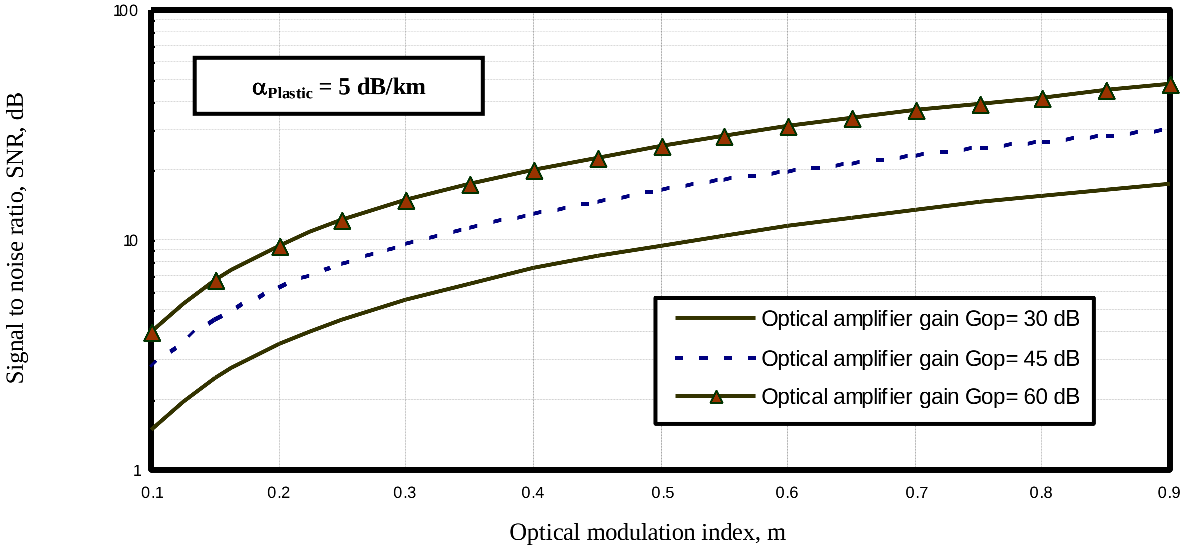

Fig. 7. Variations of signal to noise ratio against optical modulation index at the assumed set of parameters.

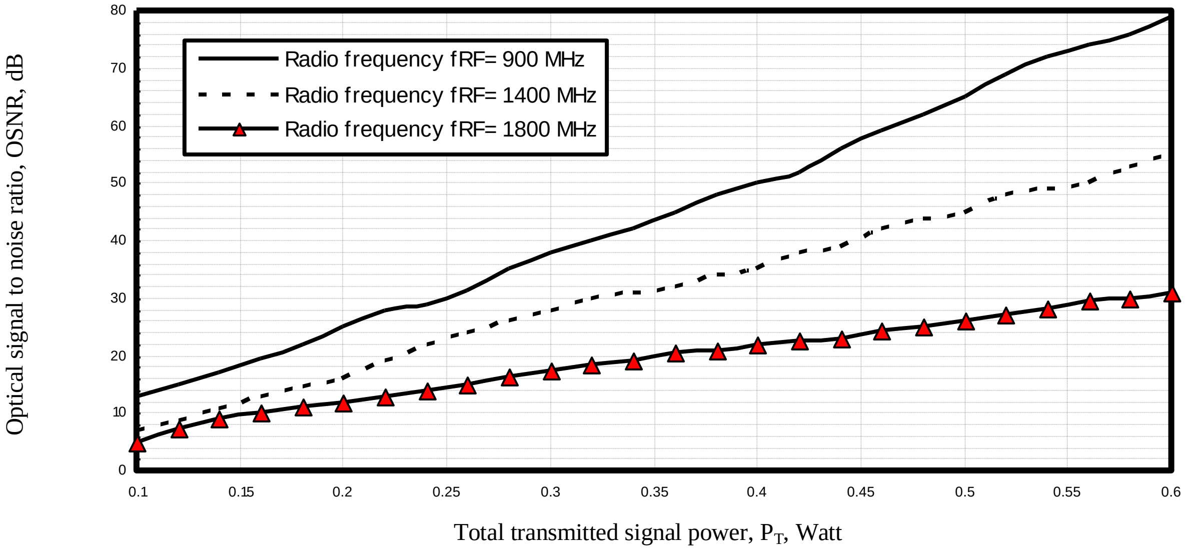

Fig. 8. Variations of the optical signal to noise ratio against total transmitted signal power at the assumed set of the parameters.

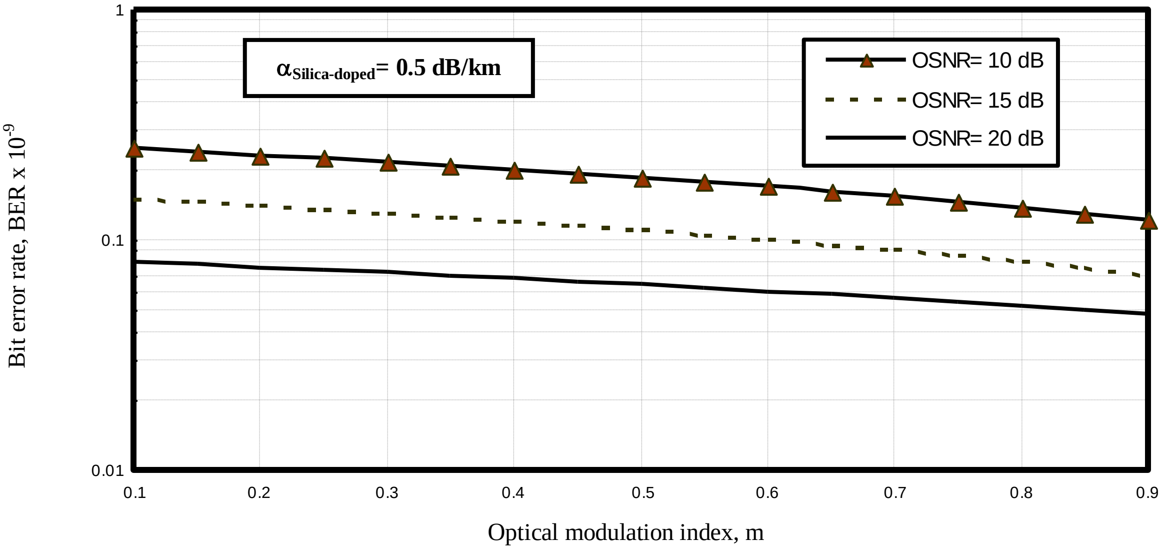

Fig. 9. Variations of bit error rate against optical modulation index at the assumed set of parameters.

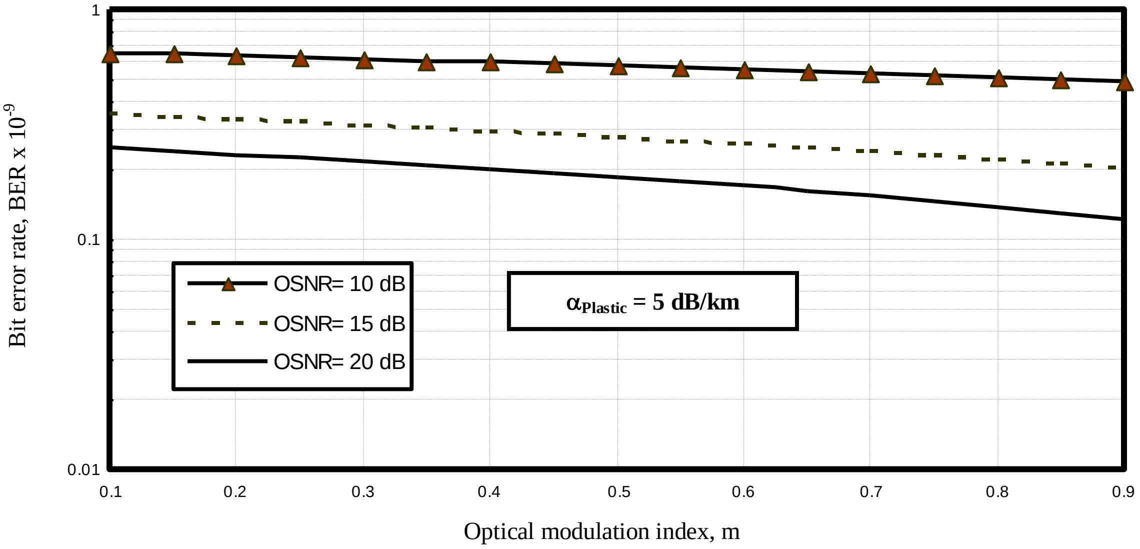

Fig. 10. Variations of bit error rate against optical modulation index at the assumed set of parameters.

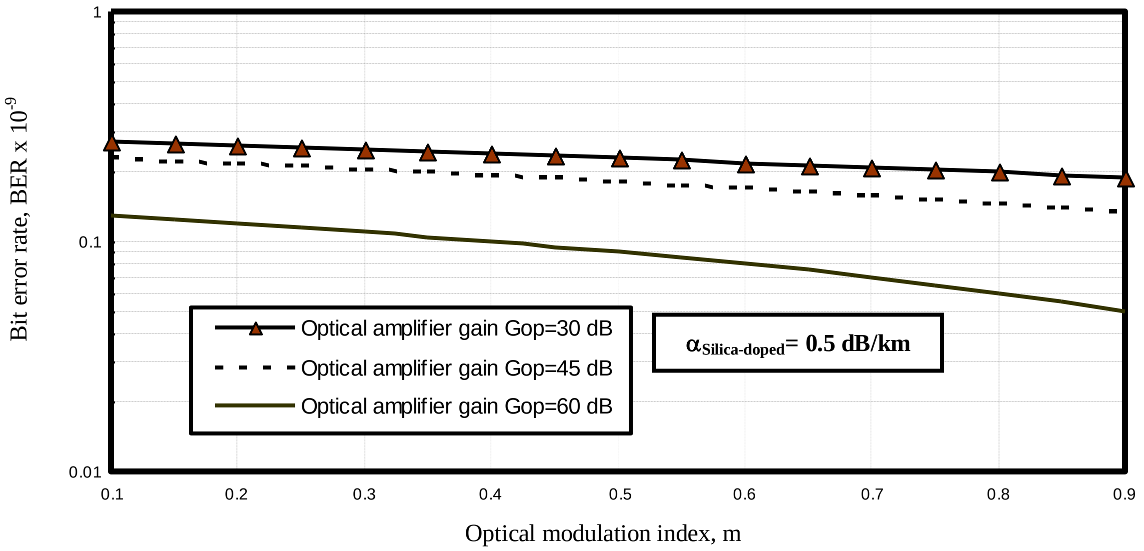

Fig. 11. Variations of bit error rate against optical modulation index at the assumed set of parameters.

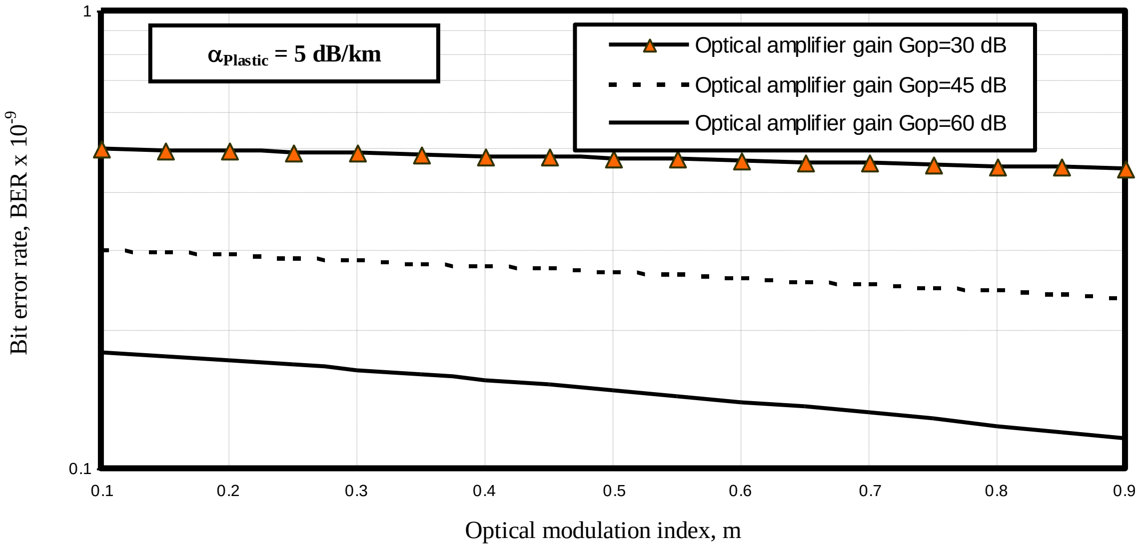

Fig. 12. Variations of bit error rate against optical modulation index at the assumed set of parameters.

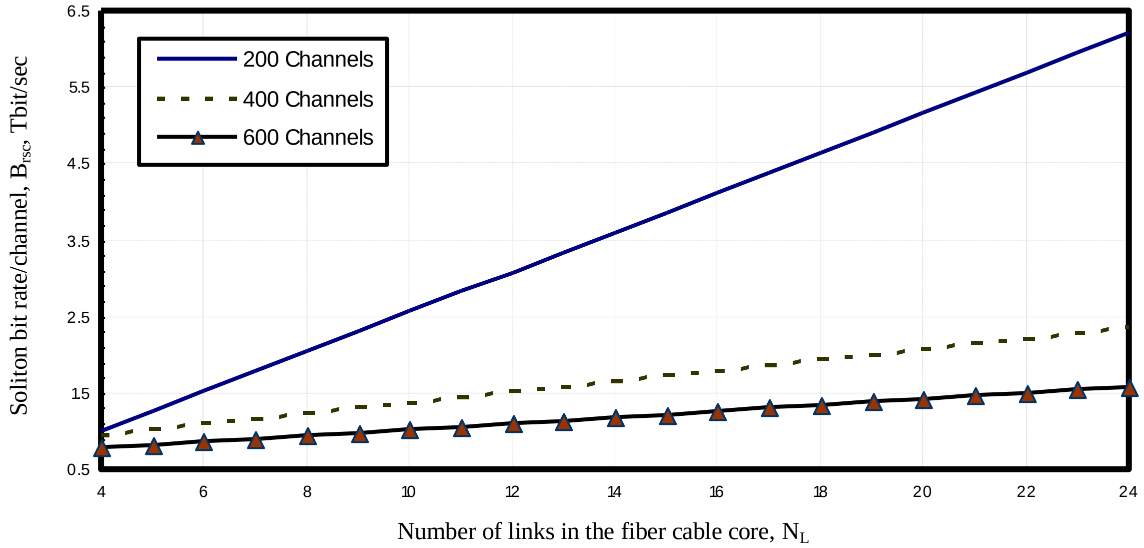

Fig. 13. Variations of soliton bit rate per channel against number of links at the assumed set of parameters.

IV. CONCLUSIONS

ROF transmission capacity for optical access communication network applications within transmission technique named soliton propagation technique; two multiplexing techniques named SDM and DWDM. The increased fiber link length, radio frequency, number of connectors, splices, and splitters, this lead to the increased total optical losses. The increased number of links in the fiber cable core, the decreased fiber temperature, and the decreased fiber link length, this result in the increased transmission bit rates. We have compared our ROF transmission systems with simulation results as in Ref. [19] as shown in Table 2. It is very clear and observed from the comparison, radio over fiber transmission systems have presented the best performance, efficiency and the highest transmission bit rates.

Table 2: Comparison Our ROF transmission system with Simulation results as in Refs. [19].

<table>
<tr><td rowspan="3"></td><td>Transmission bit rates and products with ROF transmission systems</td><td>Simulation results for transmission bit rates and products as in Ref. [19]</td></tr>
<tr><td colspan="2">Same conditions of operation</td></tr>
<tr><td colspan="2">- Ambient temperature T= 300 K-340 K, Number of transmitted channels= 100-600 channels, - Relative refractive-index difference Δn=0.007, Number of links in the fiber cable core N_L=4-24, Fiber link length= 20 km, Effective area of fiber A_{eff}= 85 μm^2.</td></tr>
<tr><td>Transmission Techniques</td><td>ROF system without amplification</td><td>Transmission Bit rates and products with backward pumping Raman amplification</td></tr>
<tr><td>Soliton bit rate/channel</td><td>3 Tbit/sec</td><td>0.956 Tbit/sec</td></tr>
</table>

REFERENCES

[1] J. Ma, J. Yu, C. Yu, X. Xin, J. Zeng, and L. Chen, “Fiber Dispersion Influence on Transmission of the Optical Millimeter Waves Generated Using LN-MZM Intensity Modulation,” J. of Ligthwave Technol., Vol. 25, No. 2, pp. 3244–3256, 2007.

[2] A. C. Sodre, D. C. Valente, M. A. Q. R. Fortes, L. F. da Silva, O. C. Branquinho, and M. L. F. Abbade, “Performance Analysis of A radio over Fiber System Based EEE 802.15.4 Standard in A real Optical Network,” Microwave and Optical Technology Letters, Vol. 51, No. 8, pp. 1876-1879, Aug. 2009.

[3] W. Fleming, “Dispersion in GeO$_2$-SiO$_2$ Glasses,” Applied Optics, Vol. 23, No. 24, pp. 4486-4493, 1985.

[4] G. Yabre, “Theoretical Investigation on the Dispersion of Graded-Index Polymer Optical Fiber,” Journal of Lightw. Technol., Vol. 18, No. 16, pp. 869-882, 2000.

[5] Ahmed Nabih Zaki Rashed, Abd El-Naser A. Mohammed, Abd El-Fattah A. Saad, “High Channel Arrayed Waveguide Grating (AWG) in Wavelength Division Multiplexing Passive Optical Networks (WDM-PONs),” IJCSNS International Journal of Computer Science and Network Security, Vol. 9, No. 1, pp. 253-259, Jan. 2009.

[6] S. S. Walker, “Rapid Modeling and Estimation of Total Spectral Losses in Optical Fibers,” J. Lightwave Technol., Vol. 4, No. 8, pp. 1125-1131, August 1986.

[7] T. Kaino, “Absorption Losses of Low Loss Plastic Optical Fibers,” J. Appl. Phys., Vol. 24, No. 3, pp.1661-1669, 1985.

[8] Ahmed Nabih Zaki Rashed, Abd El-Naser A. Mohammed, Abd El-Fattah A. Saad, “Matrices of the Thermal and Spectral Variations for the fabrication Materials Based Arrayed Waveguide Grating Devices,” International Journal of Physical Sciences, Vol. 4, No. 4, pp. 205-211, Apr. 2009.

[9] X. N. Fernando and A. B. Sesay, “Characteristics of Directly Modulated ROF Link for Wireless Access,” Canadian Conference on Electrical and Computer Engineering, Vol. 4, pp. 2167 – 2170, 2004.

[10] Yang, Y., C. Lou, H. Zhou, J. Wang, and Y. Gao, “Simple pulse compression scheme based on filtering self-phase modulation broadened spectrum and its application in an optical time-division multiplexing systems,” Appl. Opt., Vol. 45, 7524–7528, 2006.

[11] X. N. Fernando and A. Anpalagan “On The Design of Optical Fiber Based Wireless Access Systems,” IEEE Communication Society, Vol. 14, No. 2, pp. 3550-3555, 2004.

[12] W. Domon, and K. Emura, “Reflection Induced Degradations In Optical Fiber Feeder for Micro Cellular Mobile Radio Systems,” IEICE Transactions on Electronics, Vol. E76-C, No. 2, pp. 287–291, 1993.

[13] Z. Jia, J. Yu, A. Chowdhury, G. Ellinas, and G. K. Chang, “Simultaneous Generation of Independent Wired and Wireless Services Using a Single Modulator in Millimeter-Wave-Band Radio-Over-Fiber Systems,” IEEE Photon. Technol. Lett., Vol. 19, No. 20, pp.1691-1693, Oct. 2007.

[14] R. E. Wagner, J. R. Igel, R. Whitman and M. D. Vaughn, “Fiber Based Broadband Access Deployment in the United States”, IEEE J. Lightwave Technology, Vol. 24, No. 3, pp. 4526-4540, 2006.

[15] S. Alabady, O. Yousif, “Design and Simulation of an Optical Gigabit Ethernet Network,” Al-Rafidain Engineering, Vol. 18, No. 3, pp. 46-61, June 2010.

[16] B. Biswas, and S. Konar, “Soliton To Solitons Interaction With Kerr Law Non Linearity,” Journal of Electromagnetic Waves and Applications, Vol. 19, No. 11, pp. 1443–1453, 2005.

[17] S. Sawetans, and S. Konar, “Propagation of a mixture of Modes of Laser Beam in A medium With Securable Nonlinearity,” Journal of Electromagnetic Waves and Applications, Vol. 20, No. 1, pp. 65–77, 2006.

[18] R. Gangwar, S. P. Singh, and N. Singh, “Soliton Based Optical Communication,” Progress In Electromagnetics Research, PIER Vol. 74, No.3, pp. 157–166, 2007.

[19] Ahmed Nabih Zaki Rashed, Abd El-Naser A. Mohammed, and Mahmoud M. Eid, “Important Role of Optical Add Drop Multiplexers (OADMs) With Different Multiplexing Techniques in Optical Communication Networks,” International Journal of Computing, Vol. 9, No. 2, pp. 152-164, 2010.