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High Transmission Capacity Performance of Radio Over Fiber System for Short and Long Distances

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Abstract*— Transport the radio frequency (RF) signals over short range transmission applications within multimode graded index polymer optical fibers and over long range transmission within single-mode silica-doped fibers. The high transmission capacity performance of radio over Fiber (ROF) for short and long distances due to its broad-bandwidth and low attenuation characteristics has been investigated. Also we have investigated parametrically and numerically the high performance of ROF communication systems over traditional optical communication systems by using different affected parameters and we have analyzed the transmission bit rates and products (bit rate x transmission distance) based on the single mode silica doped and multimode graded index polymer fibers for using the maximum time division multiplexing and pulse code modulation techniques. The coarse wavelength division multiplexing (CWDM) and dense wavelength division multiplexing (DWDM) techniques are taken into account.

Index Terms*— ROF, DWDM, CWDM, Single mode fibers, Multimode polymer fibers, and Long haul Applications .

I. INTRODUCTION

A promising method in networks building is the use of two technologies – wireless optical communication and optical wire communication. The advantage of the use of such networks is that the wireless technology provides the frequency for signals between base stations. It is recommended due to mobility, easy use and low cost and avoids limitations connected with bandwidth of optical technologies which are used in transport network. For example networks, which consist of the integration of wireless and fiber networks, known as Radio-over-Fiber. Radio-over-Fiber technology combines wireless and fiber-optic technology to improve the efficiency of use of these technologies [1, 2].

Various schemes for RoF system have been proposed. But these are suitable for the short range application by using multimode fiber as in [3]. The single mode fiber (SMF) is avoided because of the large power loss. But compared with the conventional high frequency wireless system, ROF system shows many advantages such as low cost, high performance huge bandwidth and long distance transmission [4].

The optical millimeter-wave generation is a popular approach for RoF transmission. Several methods are discussed in the previous works by Brown et.al [4] and Yu et. al [5]. These methods are suitable for maximum of 80 km transmission [3]. The external modulation technique is suitable for the optical mm-wave generation [6]. The dispersion effect causes the degradation of the transmission performances. To reduce the effect, several approaches are developed in [7, 8].

In the present work, we have analyzed and modeled the ROF communication systems at long distances and high data rates using both RZ, and NRZ codes over wide range of the affecting parameters. We have treated it with using modified Shannon technique. Also we have deeply investigated ROF communication systems within multi mode polymer optical fibers for short transmission applications. Normally the MMF is used in short distance transmission applications within polymer optical fibers links. ROF systems have presented high transmission bit rates per transmitted channels in polymer fibers links compared to traditional communication systems.

II. SCHEMATIC VIEW OF RADIO OVER FIBER COMMUNICATION SYSTEM

Figure 1 shows a general ROF communication system architecture. At a minimum, ROF link consists of all the hardware required to impose an RF signal on an optical carrier, the fiber-optic link, and the hardware required to recover the RF signal from the carrier.

The optical carrier's wavelength is usually selected to coincide with either the 1.3 μm window [9], at which standard single mode fiber has minimum dispersion, or the 1.55 μm window, at which its attenuation is minimum. Where the E/O is the electrical to optical conversion, O/E is the optical to electrical conversion [10], and T/R is the route from transmitter to receiver. By using these large low attenuation areas for data transmission, the signal loss for a set of one or more wavelengths can be made very small, thus reducing the number of amplifiers and repeaters actually needed. In single channel long-distance experiments, optical signals have been sent over hundreds of kilometers without amplification.

Besides its enormous bandwidth and low attenuation, fiber also offers low error rates. Communication systems using an optical fiber typically operate at bit error rate (BER) of less than 10^{-11}. The small size and thickness of fiber allows more fiber to occupy the same physical space as copper, a property that is desirable when installing local networks in buildings. Fiber is flexible, reliable in corrosive environments, and deployable at short notice. Fiber transmission is immune to electromagnetic interference and does not cause interference [11].

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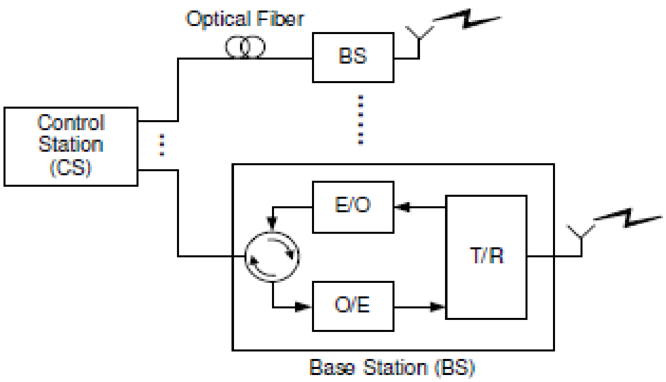

Fig. 1 ROF communication system architecture.

III. MODELING AND ANALYSIS

The optical channel of the ROF link uses a multimode fiber that consists of an optical source, a fiber, and a photodetector. The signal is directly modulated onto a laser and biased to minimize nonlinearity and clipping distortion. The signal s(t) after biased is given as [12]:

$$S_{bias}(t) = [1 + m\,s(t)] \qquad (1)$$

where m is the optical modulation index. The number of transmitted channels in the system is Nch. It comes from the relationship in the frequency domain between the total system bandwidth, the channel bandwidth and the guard bandwidth, and it is given by [13]:

$$N_{ch} = \sqrt{\frac{B.W_{Total}}{B.W_{Up} + B.W_{Down} + 2\,B.W_{Guard}}} \;, \qquad (2)$$

Where B.WUp is the bandwidth of the uplink, B.WDown is the bandwidth of the downlink, and B.WGuard is the bandwidth of the guard band. Assume that B.WUp=B.WDown, and then the desired user data rate can be expressed as:

$$BR_{User} = \frac{B.W_{Up} + B.W_{Down}}{2} \;, \qquad (3)$$

The bandwidth of the guard band for audio signal can be, B.Wguard=1 KHz, and the bandwidth of the guard band for video signal can be, B.Wguard=100 KHz. It is well known that the bandwidth can be maximized by optimizing the shape of the GI distribution of the fiber core. The index distribution is expressed by a power law [14-16]:

$$n(r) = n\left(1 - \left(\frac{r}{R_p}\right)^{g} \Delta n\right) \;, \qquad (4)$$

Where n(r) is the refractive index at radial distance r, Rp is the polymer radius of the core in µm, Δn is a parameter that can be used to measure the relative refractive-index difference, and parameter g is the exponent of the power law. Ref. [16] derived the optimum index profile as a function of g, which is expressed as follows:

$$g = 2 + \varepsilon - \frac{(4+\varepsilon)(3+\varepsilon)\Delta n}{5 + 2\varepsilon} \qquad (5)$$

The parameters to characterize the temperature and operating signal wavelength dependence of the refractive-index from empirical equation is given as by [17]:

$$n = \sqrt{1 + \frac{S_1\lambda^2}{\lambda^2 - S_2^2} + \frac{S_3\lambda^2}{\lambda^2 - S_4^2} + \frac{S_5\lambda^2}{\lambda^2 - S_6^2}} \;, \qquad (6)$$

where the first and second differentiation with respect to operating signal wavelength λ as discussed in Ref. [17]. Where the coefficients of the benzyl benzoate for PMMA (PMMA-BEN) given as follows: S1=0.4855, S2=0.1043 (T/T0) , S3= 0.7555, S4=0.1147 (T/T0), S5= 0.4252, S6= 49.34 (T/T0). Where T and T0 are the ambient temperature and room temperature along polymer optical fiber link and measured both in K. The output pulse width from the GI-POF was calculated by the solution of WKB method in which both modal and material dispersions were taken into account as shown in the following expressions [17]:

$$\sigma_{modal} = \frac{L N_1 \Delta n}{2c} A_1 A_2 \left(C_1^2 + A_3 + A_4\right)^{0.5} \qquad (7)$$

With A1=g/g+1, A2=(g+2/3g+2)0.5, A3=4C1C2Δn(g+1)/2g+1, and A4=4Δn2C2(2g+2)2/(5g+2)(3g+2). (8)

$$\sigma_{chromatic} = \frac{\sigma_s L}{\lambda}\left(A_5^2 + A_6 A_7 + A_8 A_9\right) \qquad (9)$$

With A5=-λ2d2ncore/dλ2, A6=-2 λ2d2ncore/dλ2(N1Δn), A7=C1(g/g+1), A8=(N1Δn)2(g-2-ε)/g+2, and A9=2g/3g+2. Where L is the polymer fiber link length in m, N1, ε are the group refractive index [18], profile dispersion parameter and can be expressed as follows:

$$N_1 = n - \lambda\frac{dn}{d\lambda} \;, \qquad (10)$$

$$\varepsilon = \frac{-2n}{N_1}\,\frac{\lambda}{\Delta n}\,\frac{d\Delta n}{d\lambda} \;, \qquad (11)$$

With the constants C1=g-2-ε/g+2, and C2=3g-2-2ε/2(g+2). Then the total root mean square pulse width can be:

$$\sigma_{total} = \sigma_{modal} + \sigma_{chromatic} \;, \qquad (12)$$

The power penalty of the receiver reaches one decibel when the pulse width exceeds one fourth of the bit period and therefore the possible transmission bit rate with maximum time division multiplexing can be expressed as [19, 20]:

$$B_{R(MTDM)} = \frac{1}{4\sigma_{total}} \;, \qquad (13)$$

The total system capacity or total bit rate within pulse code modulation scheme with carrier radio frequency can be expressed as follows [21]:

$$B_{R(PCM)} = 2\gamma\,(f_m + f_{RF}) = 2\,(f_m + f_{RF})\log_2 Q \qquad (14)$$

Where γ is the number of bits per sample, Q is the number of quantization levels, fm is the modulating frequency which can be ranged from 3.4 KHz–4 KHz for audio signal, and can be ranged from 6.8 MHz–8 MHz for video signal. Therefore the total system transmission capacity can be expressed as follows [22]:

$$System\ Capacity(SC) = B_R\ L \;, \qquad (15)$$

where L is the polymer fiber link length in meters.

The rise time of an optical fiber communication system Δτsystem is given by [23]:

$$\Delta\tau_{system} = \left[\sum_{i=1}^{N} \Delta\tau_i^2\right]^{1/2} \;, \qquad (16)$$

where Δτi is the rise time of each component in the system. The three components of the system that can contribute to the system rise time are as the following:

i) The rise time of the transmitting source Δτsource (typically equal to value of 16 psec).
ii) The rise time of the receiver Δτreceiver (typically equal to value of 25 psec).

iii) The material dispersion time of the fiber Δτmat which is given by the following equation:

$$\Delta\tau_{mat} = -\left(\frac{L.\Delta\lambda.\lambda}{c}\right).\left(\frac{d^2n}{d\lambda^2}\right) , \qquad (17)$$

Then the total dispersion of the optical communication system can be expressed as:

$$\Delta\tau_{system} = \Delta\tau_{source} + \Delta\tau_{receiver} + \Delta\tau_{mat} \qquad (18)$$

The bandwidth for standard single mode fibers for both materials based optical link length LF is given by:

$$B.W_{sig.} = \frac{0.44}{\Delta\tau_{system} \cdot L_F} , \qquad (19)$$

IV. SIMULATION RESULTS AND DISCUSSIONS

Based on the modeling equations analysis and the assumed set of the operating system parameters as follows: , root mean square spectral linewidth of the optical source σ_s=0.1 nm, ambient temperature T=300-330 K, room temperature T_0=300 K, polymer fiber radius R_p=500 μm, Transmitted signal power P_T=0.1 Watt–0.6 Watt, OSNR=50 dB, polymer fiber link length L=100 m–1000 m, radio frequency f_{RF}=900 MHz–1800 MHz, number of transmitted channels N_{ch}=4–20, relative refractive index difference number of quantization levels Q=4–128, Δn=0.01-0.03, index exponent g=2.5. Based on a specially designed software, and the assumed set of the series of the above operating parameters, the following facts as shown in the series of Figs. (2-13) are assured the clarified results:

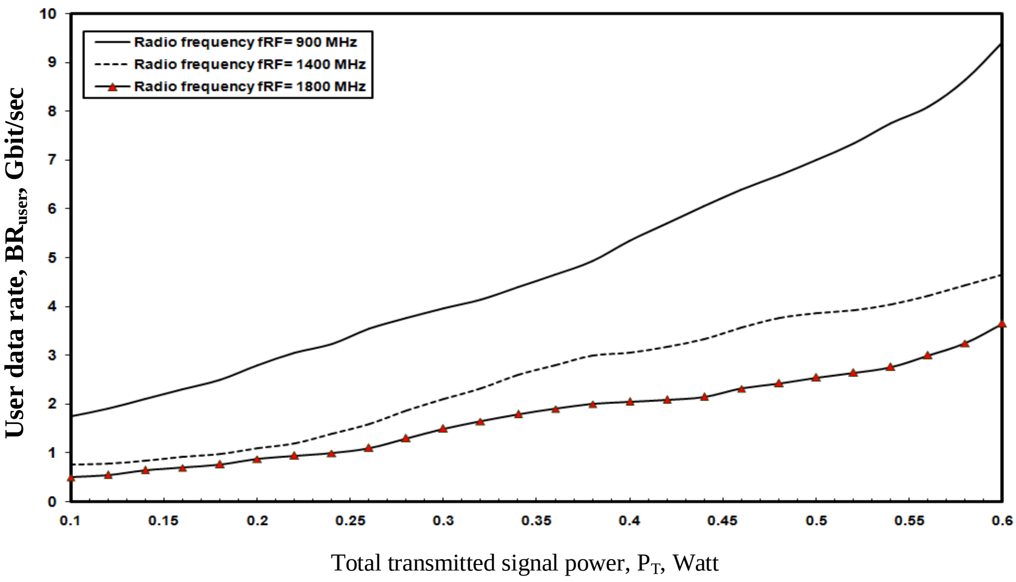

Fig. 2 Variations of the user transmission data rate against total transmitted signal power at the assumed set of the parameters.

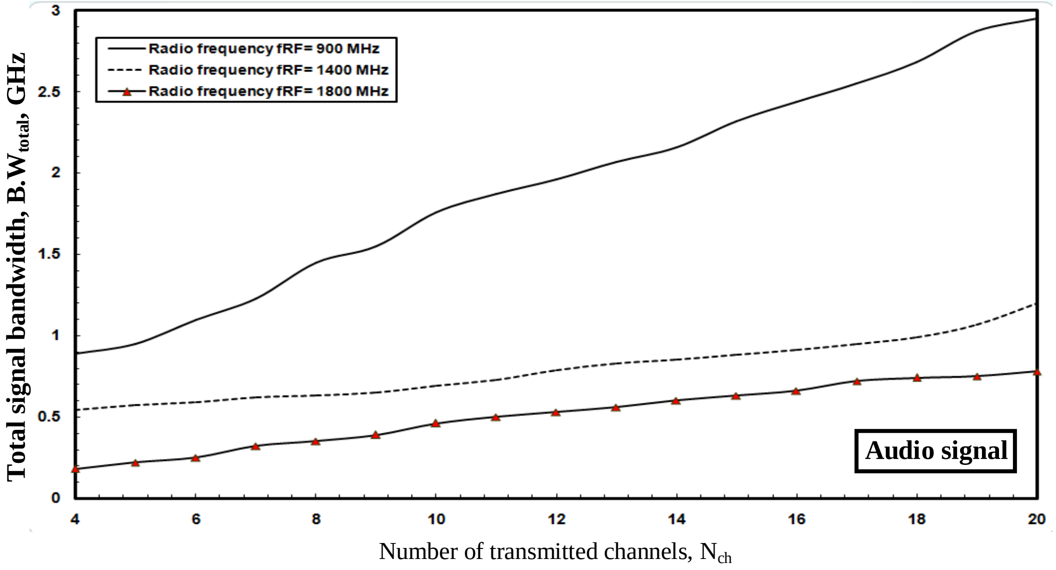

Fig. 3 Variations of the total system signal bandwidth against number of transmitted channels at the assumed set of the parameters.

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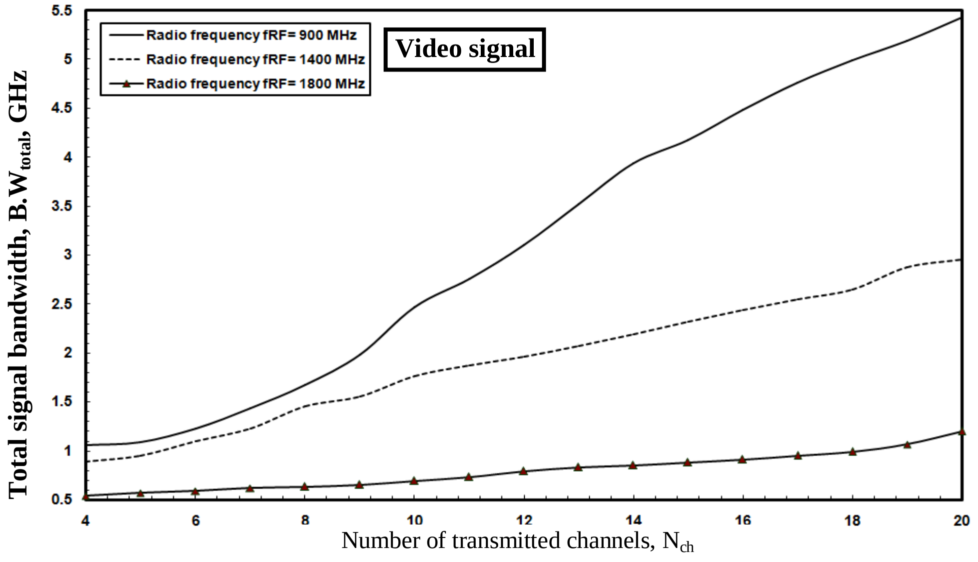

Fig. 4 Variations of the total system signal bandwidth against number of transmitted channels at the assumed set of the parameters.

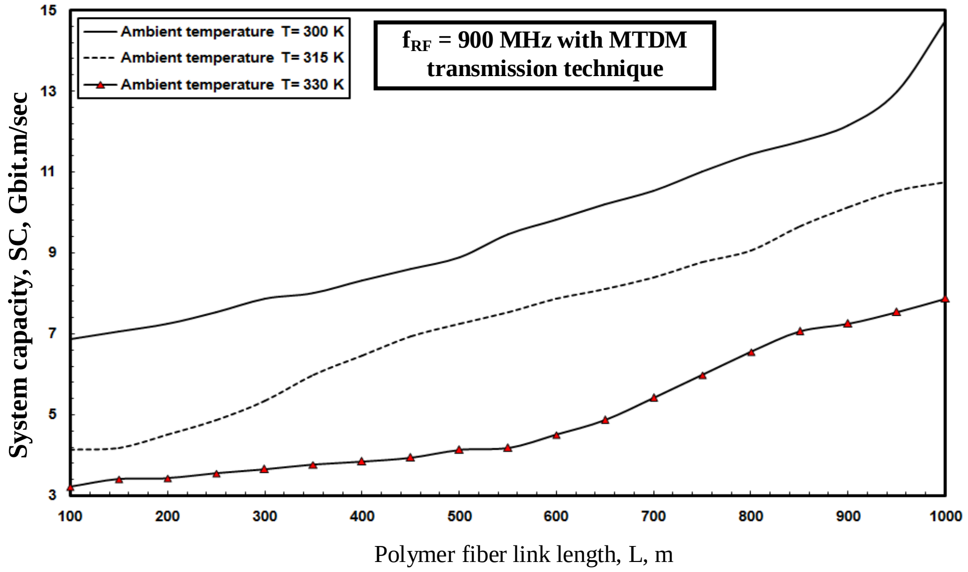

Fig. 5 Variations of the system transmission capacity against polymer fiber link length at the assumed set of the parameters.

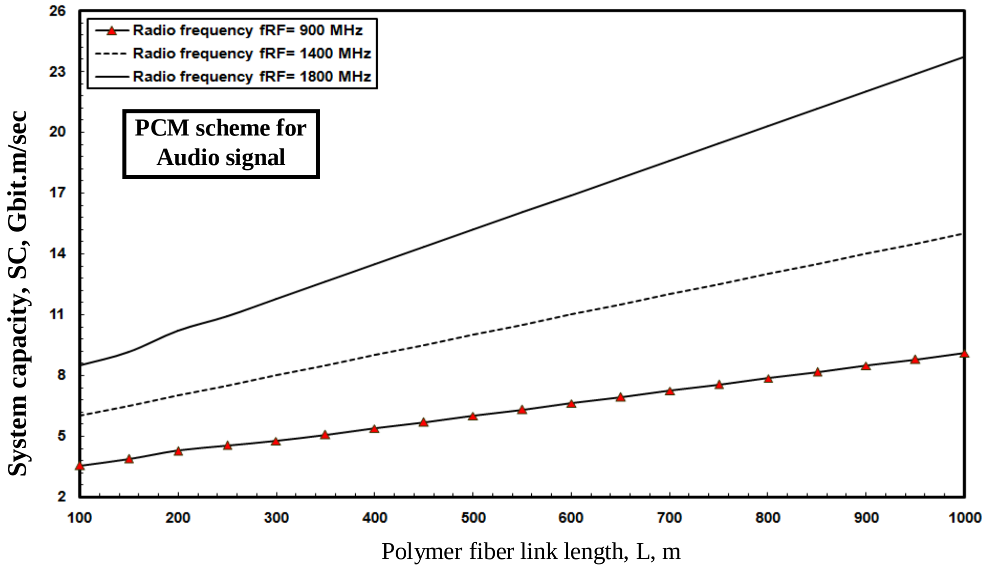

Fig. 6. Variations of the system transmission capacity against polymer fiber link length at the assumed set of the parameters.

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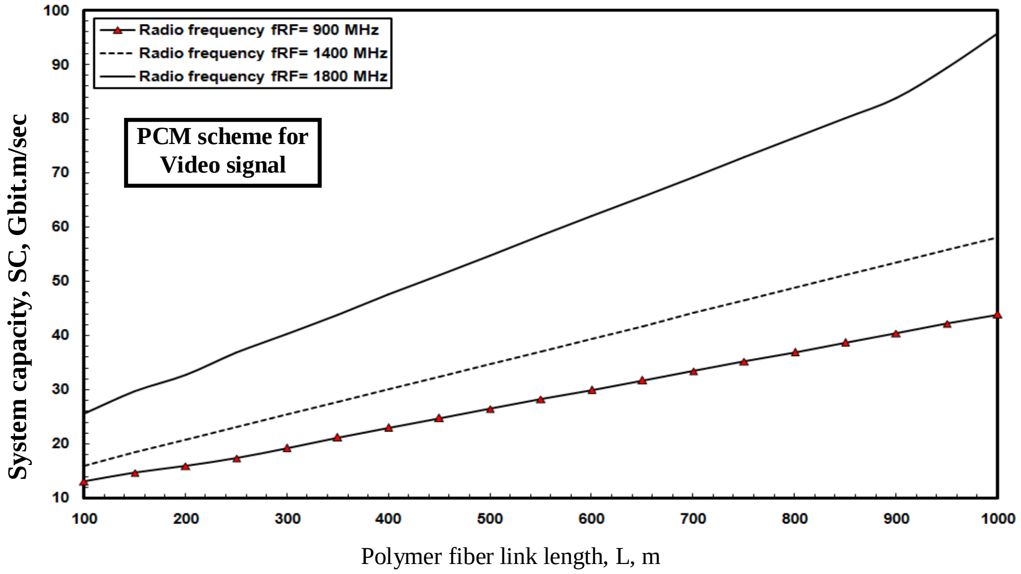

Fig. 7. Variations of the system transmission capacity against polymer fiber link length at the assumed set of the parameters.

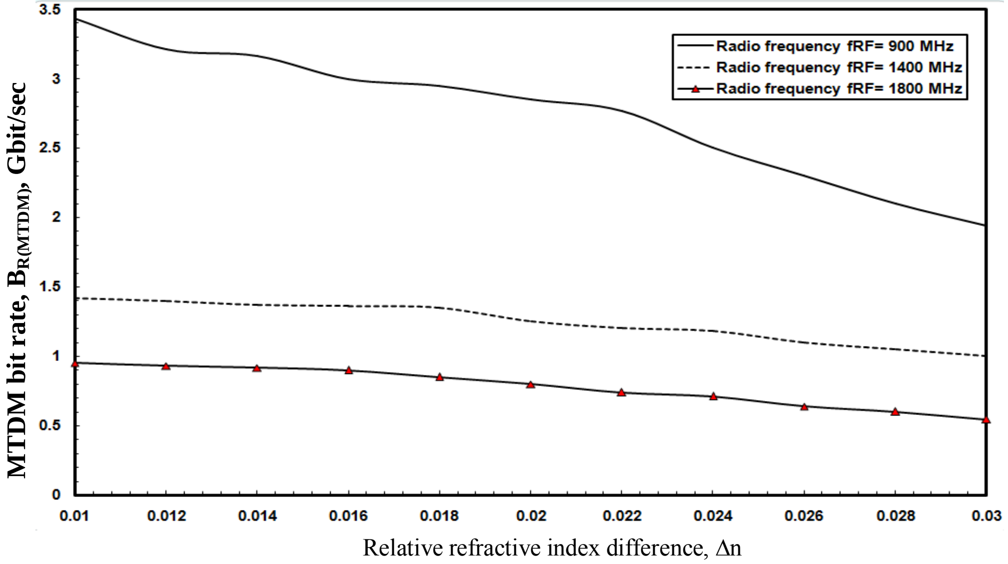

Fig. 8. Variations of MTDM transmission bit rate against relative refractive index difference at the assumed set of the parameters.

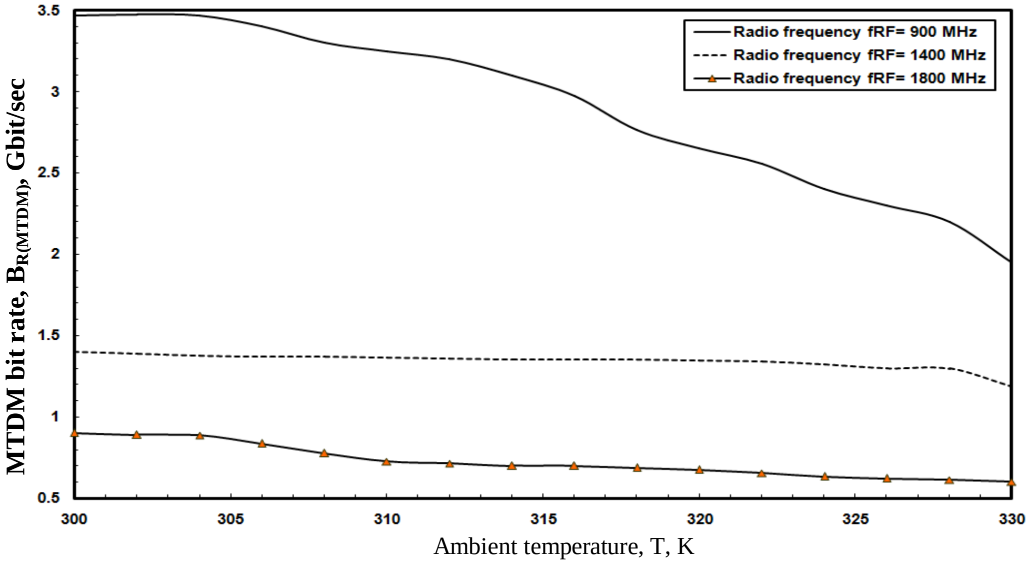

Fig. 9. Variations of MTDM transmission bit rate against ambient temperature at the assumed set of the parameters.

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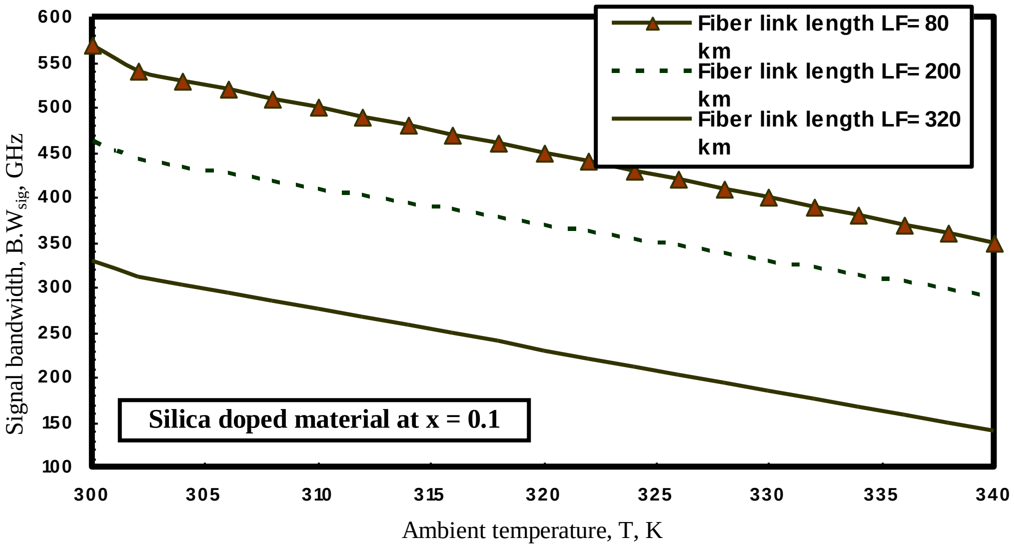

Fig. 10. Variations of transmission bit rate against ambient temperature at the assumed set of the parameters.

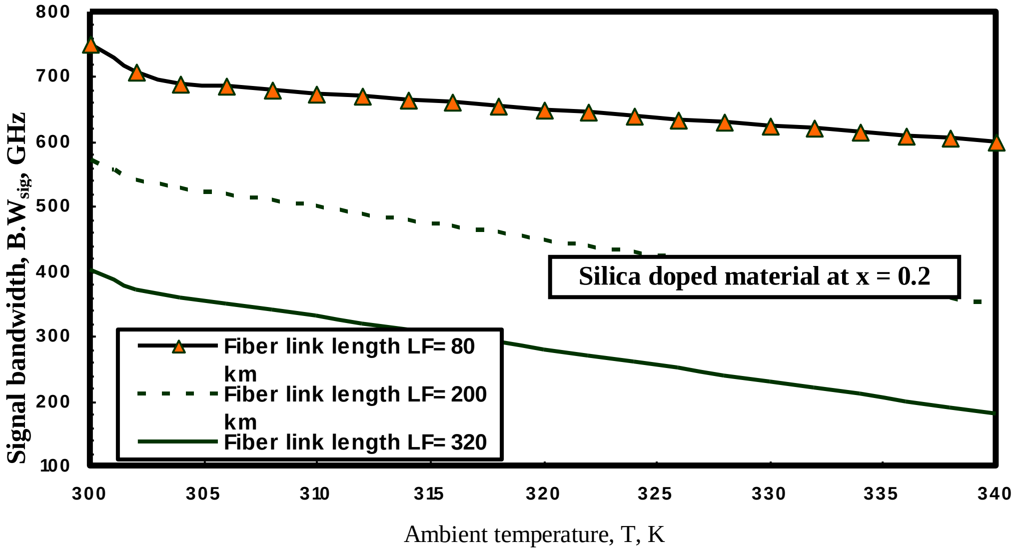

Fig. 11. Variations of transmission bit rate against ambient temperature at the assumed set of the parameters.

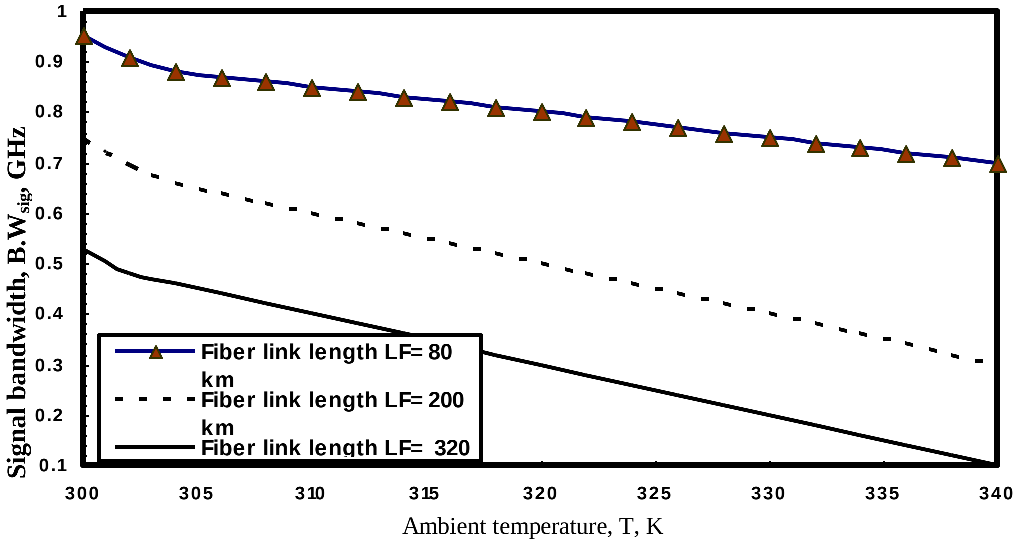

Fig. 12. Variations of transmission bit rate against ambient temperature at the assumed set of the parameters.

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V. CONCLUSIONS

In a summary, we have developed ROF communication systems within multimode polymer optical fibers with using pulse coding modulation scheme, maximum time division multiplexing transmission technique, and coarse wavelength division multiplexing technique. In order to reduce the system cost, radio over fiber technology has been proposed since it provides functionally simple base stations that are interconnected to a central control station (CS) via an optical fiber. It has the following main features: (1) it is transparent to bandwidth or modulation techniques, (2) simple and small base stations, (3) centralized operation is possible. Extensive research efforts have been devoted to the development of physical layer such as simple base station development and radio signal transport techniques over fiber. It is theoretically found that the increased of total transmitted signal power and the decreased of operating radio frequencies, the increased of both optical signal to noise ratio (OSNR) and user data transmission bit rates. As well as we have indicated that the increased number of transmitted channels, and the deceased operating radio frequencies, this results in increasing of total signal bandwidth for both audio and video signals. Moreover we have demonstrated that the decreased of both ambient temperature and relative refractive index difference, and the decreased operating radio frequencies, this leads to increase of transmission bit rates with MTDM transmission technique. It is also theoretically found that the decreased of both ambient temperature and Δn, and the increased polymer fiber link length, this results in increasing of total system capacity with using MTDM transmission technique at the highest operating radio frequencies. It is observed that the increased number of quantization levels, polymer fiber link length and operating radio frequencies, this leads to increase of transmission bit rates and total system capacity with using PCM scheme for both audio and video signals. We have observed that the video signals have presented lager total signal bandwidth and total system capacity compared to audio signals.

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