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THEORETICAL AND EXPERIMENTAL INVESTIGATION OF FIBER LOSS AND DISPERSION EFFECTS IN OPTICAL NETWORKS

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ABSTRACT

In this paper the transmission limitations due to the fiber loss and dispersion in optical networks have been investigated, theoretically and experimentally, for three different fibers. An approach for computing the maximum allowable transmission distance imposed by the fiber loss and dispersion as a function of bit rate has been developed. It is found that fiber loss is the dominant factor that determine maximum allowable transmission distance at low bit rate. However, as the bit rate increases, fiber dispersion rather than fiber loss is the factor which determines the maximum allowable transmission distance. By comparing the three fibers under study, it is found that, 850nm fiber is the worst in terms of transmission distance, while the 1550nm has superiority over the 1330nm for bit rate <9.5Gb/s. However, for bit rate >9.5Gb/s the 1330nm fiber is better in terms of bit rate and transmission distance. Experimental results for the three fibers (850nm, 1300nm and 1550nm) show a good agreement between the analytical and experimental.

Keywords: Fiber optic communication, attenuation, dispersion, optical networks.

I. INTRODUCTION

The first generation light wave systems operating near 800nm started early in the 70's. During that period of time, it was realized that the repeaters spacing could be increased by operating the light wave system in the wavelength region near 1300nm, where the fiber loss is generally below 1dB/ km. The second generation of fiber optic communication systems became available and allowed a repeaters spacing in excess of 20km. However, the bit rate of early systems was limited to below 100Mb/s because of modal dispersion in multimode fibers (MMFs). This limitation was overcome by the use of single-mode fibers (SMFs).

The third generation systems of 1550nm become available commercially. In such systems, the limiting factors are frequency chirping and the occasional transient of secondary laser mode, both factors lead to errors in the presence of fiber dispersion. A better performance is achieved by using dispersion-shifted fibers (DSFs). The fourth generation of light wave systems is concerned with an increase in the bit rate through frequency-division multiplexing and respective wave-division multiplexing techniques, and an increase in the repeaters spacing through optical amplification [1-8]. The fifth generation of fiber optic communication systems is based on the concept of fiber soliton, optical pulses that preserve their shape during propagation in fiber loss by counteracting the effect of dispersion through the fiber nonlinearity and using erbium-doped fiber amplifiers to compensate fiber loss. Therefore, investigation of fiber dispersion is very important task in the design of optical communication networks and many authors have been studied this matter [9-13].

The limitation of using only a small fraction of the tremendous bandwidth of optical fiber is due to the combined effect of loss and dispersion. To get rid of the intrinsic loss of the fiber, there is a necessity to amplify the soliton pulses periodically. In the past, frequent regeneration was imposed by fiber attenuation and the need to convert the optical signal into electrical for amplification.

Recently, an increase interest has been made to develop ultra-high bit rates and ultra-long distance optical soliton transmission systems based on an eminently practical optical amplifier, such as the Erbium doped fiber amplifier (EDFA). These EDFAs are in-line amplifier, which could be either lumped or distributed. The advantage of regeneration is to avoid or mitigate the accumulation of signal impairments like optical noise, linear distortion and nonlinearities which impinging the performance of the optical systems.

Chromatic dispersion, or more precisely group velocity dispersion (GVD) can cause pulse spreading in lightwave signals, it can be considered as one of the major limiting factors in high bit rate transmission systems operating over standard single mode fiber (SMF). In long and high-speed optical fiber communication systems, GVD limits the achievable bit rate–distance product (*BL*). Moreover, the ultimate capacity limitations of high channel speed systems are determined by the interaction of the chromatic dispersion and nonlinearities in optical systems [13–17].

II. THEORETICAL ANALYSIS

Fiber optics can be classified into two broad categories, namely multimode and single-mode fibers. Under the condition that , the gathering capacity of an optical fiber is characterized by numerical aperture (*NA*), which can be expressed as:

$$NA = n_1 (2\Delta)^{1/2} \quad (2.1)$$

$$\Delta = (n_1 - n_2)/n_1 \quad (2.2)$$

where n_1 and n_2 are the refraction indices of the fiber core and cladding respectively. Δ is the fractional index change at the interface core cladding.

To couple maximum light into the fiber, Δ should be as large as possible. However, this is not useful for optical communication networks because of intermodal dispersion, which occurs because different rays travel along paths of different lengths. The shortest path is just equal to the fiber length, while the largest path has a length $L/sin\varphi_c$, where φ_c is the critical angle for which the ray experiences total internal refraction at the core cladding interface and is given by $sin\varphi_c = n_1/n_2$. By introducing the velocity propagation $v = c/n_1$, the time delay , ΔT, is given by [18]:

$$\Delta T = \frac{\Delta L}{v} = \frac{n_1}{c}(L/sin\varphi_c - L) = \frac{L}{c}\frac{n_1^2}{n_2}\Delta . \quad (2.3)$$

ΔT is a measure of broadening experienced by impulse launched at the fiber input, which can be related to the information carrying capacity of the fiber through the bit rate, *B*. For the case where ΔT is less than the allocated bit slot ($T_B=1/B$), and from the condition $B\Delta T < 1$, *BL* was obtained [18]:

$$BL \le \frac{n_2}{n_1^2}\frac{c}{\Delta} . \quad (2.4)$$

Equation (2.4) provides a rough estimation of transmission distance for step index fiber with $a >> \lambda$, where *a* is the core radius of the fiber and λ is its wavelength. In the case of 850nm light wave systems, which commonly use multimode fiber to minimize the system cost, a more restrictive condition is used given by [18]:

$$BL = \frac{c}{2n_1\Delta} \quad (2.5a)$$

and in the case of graded index, the estimated transmission distance is given as [18]:

$$L_{max} = \frac{8c}{B\, n_2 \Delta^2} . \quad (2.5b)$$

The second generation of light wave systems used single-mode fibers near the minimum dispersion occurring near 1300nm. The limitation imposed on the bit rate and the transmission distance by fiber dispersion depends on the source spectral width. One of the dispersion parameters is the group velocity dispersion, which leads to pulse broadening because different components disperse during propagation and become desynchronized at the fiber output.

In a single-mode fiber of length *L* a specific spectral component of frequency ω would arrive at the output end of the fiber after a time delay L/v_g, where v_g is the group velocity defined as:

$$v_g^{-1} = d\beta/d\omega . \quad (2.6)$$

By using $\beta = \tilde{n}k_o = \tilde{n}\omega/c$, we obtain $v_g = c/\tilde{n}_g$, where β is the propagation constant of the mode, k_o is the free space wave number defined by $k_o=\omega/c=2\pi/\lambda$, and $\tilde{n}$ is the mode index (or effective index). It has the physical significance that the mode propagates with an effective refractive index $\tilde{n}$ whose value lies in the range $n_1 > \tilde{n} > n_2$. The group index $\tilde{n}_g$ is given by:

$$\tilde{n}_g = \tilde{n} + \omega (d\tilde{n}/d\omega) . \quad (2.7)$$

A mode ceases to be guided when $\tilde{n} \le n_2$ i.e. the mode is said to reach cutoff, that is:

$$V = k_o a(n_1^2 - n_2^2)^{1/2} \approx (2\pi/\lambda) a n_1 \sqrt{2\Delta} . \quad (2.8)$$

This parameter is also called normalized frequency, or simply the *V* parameter, and is related to the normalized propagation constant by the following relationship:

$$b = \frac{\beta/k_o - n_2}{n_1 - n_2} = \frac{\tilde{n} - n_2}{n_1 - n_2} . \quad (2.9)$$

In frequency domain, for a frequency spread ($\Delta\omega$), the pulse broadening is governed by the following relation:

$$\Delta T = \frac{dT}{d\omega}\Delta\omega = L\frac{d}{d\omega}\left(\frac{1}{v_g}\right)\Delta\omega = L\frac{d^2\beta}{d\omega^2} = L\beta_2\Delta\omega . \quad (2.10)$$

The parameter $\beta_2 = d^2\beta/d\omega^2$ is the group velocity dispersion. It determines how much an impulse would broaden on propagation inside the fiber. The third order dispersion parameter β_3 is related to β_2 *by* $\beta_3 = d\beta_2/d\omega = d^3\beta/d\omega^3$. In optical communication systems, $\Delta\omega$ is determined by the range of wavelength, $\Delta\lambda$, emitted by the optical source. It is customary to use $\Delta\lambda$ in place of $\Delta\omega$. By substituting $\omega = 2\pi c/\lambda^2$ and $\Delta\omega = (-2\pi c/\lambda^2)\Delta\lambda$ into equation (2.10), we get:

$$\Delta T = L\frac{d}{d\lambda}\left(\frac{1}{v_g}\right)\Delta\lambda = -\frac{2\pi c}{\lambda^2}\beta_2 L\Delta\lambda = DL\Delta\lambda \quad (2.11a)$$

$$D = -\frac{2\pi c}{\lambda^2}\beta_2 \quad (2.11b)$$

where *D* is the dispersion parameter. The *D* parameter can be written as $D=D_M+D_\omega$, where the material dispersion D_M and the wave guide dispersion D_ω are given by [19]:

$$D_M = -\frac{2\pi}{\lambda^2}\frac{dn_{2g}}{d\omega} = \frac{1}{c}\frac{dn_{2g}}{d\lambda} \quad (2.12)$$

$$D = \frac{2\pi\Delta}{\lambda^2}\left[\frac{n_{2g}^2}{n_2\omega}\frac{Vd^2(Vb)}{dV^2} + \frac{dn_{2g}d(Vb)}{d\omega dV}\right] \quad (2.13)$$

where n_{2g} is the group index of the cladding material and the parameters *V* and *b* are as defined before.

Generally, the broadening factor is defined as the ratio of σ/σ_o. For Gaussian source spectrum with a root-mean square (RMS) width σ_ω, it is possible to obtain the broadening factor in analytic form as [20-21]:

$$\frac{\sigma}{\sigma_0}=\left[\begin{array}{c}\left(1+\frac{C\beta_2 L}{2\sigma_0^2}\right)^2+\left(1+F^2\right)\left(\frac{\beta_2 L}{2\sigma_0^2}\right)+\\ \frac{1}{8}\left(1+C^2+F^2\right)^2\left(\frac{\beta_3 L}{2\sigma_0^2}\right)^2\end{array}\right]^{1/2} \quad (2.14)$$

where L is the fiber length, $F=2\sigma_\omega\sigma_0$, and $\sigma_0=T_0/\sqrt{2}$ is the RMS width of the chirped Gaussian pulse, T_0 represents the half-width at $\mathbf{e}^{-1}$ intensity point and is related to the full width at half-maximum (FWHM) by the relation [22] $T_{FWHM}=2(\mathbf{ln}2)^{1/2}\approx 1.665T_0$, σ is the RMS width of the pulse defined by $\sigma=[\langle t^2\rangle-\langle t\rangle^2]^{1/2}$. The parameter C governs the linear chirp imposed on the pulse, and the spectral width is enhanced by a factor of $(1+C^2)^{1/2}$. Note that, the high–order depressive effects play a significant role only if $T_0\left|\beta_2/\beta_3\right|\le 1$ Equation (2.14) describes broadening of chirped Gaussian pulses in a linear depressive medium for general conditions. It is used in the following section to discuss the effect of group velocity dispersion on the performance of the fiber optic communication systems.

III. LIMITATION DUE TO DISPERSION

The group velocity dispersion (GVD) limits the bit rate B and the transmission distance L of the fiber-optic communication systems. The bit rate-distance product is considered as a useful measure of the information-transmission capacity of the optical system. BL is limited by the GVD, and the amount of limitations depends on the source and pulse spectral widths. Each of which can be discussed separately.

III.1 Limitations Due To Source Spectral Width

First consider the case where F>>1, that is the pulse broadening is dominated by the large spectral width σ_ω of the source. For a Gaussian pulse, the broadening factor is obtained from equation (2.14). Assuming that the contribution of the third order of the GVD, β_3 is negligible and the chirping factor $C=0$. Then the RMS pulse width σ is obtained from equations (2.14) and (2.11.b) as:

$$\frac{\sigma}{\sigma_0}=\left[1+\left(\frac{\beta_2 L\sigma_\omega}{\sigma_0}\right)^2\right]^{\frac{1}{2}}=\left[1+\left(DL\sigma_\lambda/\sigma_0\right)^2\right]^{1/2} \quad (3.1)$$

where σ_λ is the RMS value of the spectral width in wavelength units, σ can be related to B by using the criterion which states that the broadened pulse should remain inside the allocated bit slot ($T_B=1/B$). For Gaussian pulse, the limiting bit rate is $4B\sigma\le 1$. In the case of short input pulse ($\sigma_0<<\sigma$) the condition becomes:

$$BL\left|D\right|\sigma_\lambda\le 1/4. \quad (3.2)$$

In fiber optic communication systems operating near 1.55µm, using DSFs in which the minimum loss wavelength and the zero-dispersion wavelength nearly coincide can reduce the effects of GVD. This reduction in loss and dispersion results in considerable improvement in the system performance. In the case when operating exactly at the zero-dispersion wavelength ($\beta_2=0$), the limiting BL is obtained by following the same steps used to obtain equation (3.2). Now, the broadening factor is given by [18]:

$$\frac{\sigma}{\sigma_0}=\left[1+\frac{1}{2}\left(\frac{\beta_3 L\sigma_\omega^2}{\sigma_0}\right)^2\right]^{1/2}=\left[1+\frac{1}{2}\left(SL\sigma_\lambda^2/\sigma_0\right)^2\right]^{1/2} \quad (3.3)$$

where, S is the dispersion slope given by $S=dD/d\lambda$ and it is related to the β_2 and β_3 by the following relationship [19]:

$$S=\left(2\pi c/\lambda^2\right)^2\beta_3+\left(2\pi c/\lambda^3\right)\beta_2. \quad (3.4)$$

For a source of spectral width $\Delta\lambda$, the effective value of dispersion parameter becomes $D=S\Delta\lambda$. Since that $\beta_2=0$ and S is proportional to β_3, therefore, the output pulse width given by equation (3.3) can be written as $\sigma_0=\left(\sigma_0^2+\sigma_D^2\right)^{1/2}$, where $\sigma_D=L\left|S\right|\sigma_y^2\sqrt{2}$. The limiting bit rate is obtained from the criterion $4B<1$, and for $\sigma<<\sigma_D$ is given by:

$$BL\left|S\right|\sigma_\lambda^2\le 1/\sqrt{8}. \quad (3.5)$$

III.2 Limitation Due To Pulse Spectral Width

Here, it is considered that F<<1 in equation (2.14), i.e., σ_ω is much smaller than pulse spectral width. Neglecting β_3 term and setting $C=0$, equation (2.14) can be approximated by [23]:

$$\sigma=\left[\sigma_0^2+\left(\beta_2 L/2\sigma_0\right)^2\right]^{1/2}=\left(\sigma_0^2+\sigma_D^2\right)^{1/2}. \quad (3.6)$$

Comparing equations (3.1) and (3.6), it is clear that the dispersion induced broadening depends on σ_o, whereas it is independent of σ_o when the spectral width of the optical source dominates. In order to reduce the broadening, σ has to be minimized by choosing an optimum value of σ_o. Indeed, the minimum value of σ is found to occur for $\sigma_0=\sigma_D=(|\beta_2|L/2)^{1/2}$ and is given by $\sigma_0=(|\beta_2|L)^{1/2}$. Then, by using the criterion $4B\sigma\le 1$, the limiting bit rate is obtained as:

$$B\sqrt{\beta_2 L}\le 1/4. \quad (3.7)$$

Comparing equation (3.7) with equation (3.2) it is noted that B scales as $L^{-1/2}$ rather than L^{-1}, respectively. For light wave systems operating at the zero-dispersion wavelength and using F<<1, $C=0$, $\beta_2=0$ and applying the procedure explained in the previous subsection, we obtain the following expression for the pulse width as [23]:

$$\sigma_0=\left[\sigma_0^2+\frac{1}{2}\left(\beta_3 L/4\sigma_0^2\right)^2\right]^{1/2}=\left(\sigma_0^2+\sigma_D^2\right)^{1/2}. \quad (3.8)$$

Similar to that of equation (3.7), σ is minimized by optimizing the input pulse width σ_o. In fact, the minimum value of σ_0 occurs for $\sigma_0=\left(\left|\beta_3\right|L/4\right)^{1/3}$. Finally, the liming bit rate is obtained by using the condition that $4\beta\sigma\le 1$ and is given by [18]:

$$B(|\beta_3|L)^{(1/3)}\le 0.324. \quad (3.9)$$

In this case B scales to L as $L^{-1/3}$.

IV. LOSS LIMITATIONS

Generally, power attenuation inside an optical fiber is governed by $dp/dz=-\alpha p$, where α is the attenuation coefficient, P is the optical power, and z is the distance. If P

is the power launched at the input of a fiber of length L, then the output power P_{out} is given by [24]:

$$P_{out} = P_{in} e^{-\alpha L} \; . \qquad (4.1)$$

Usually, the fiber loss α is expressed in dB/km. For normal transmission, a limit is set on the length of the cable that can be used to ensure that the receiver circuitry can reliably detect and interpret the received attenuated signal.

For Bit Error Rate (BER) to be less than 10^{-9}, which is the standard value of error in optical systems, the number of photons (N_P) must exceed 20. This requirement is a direct result of quantum fluctuations associated with the incoming light, and it is referred to as the quantum limit, i.e, each 1 bit must contain at least 20 photons in order to be detected with BER<10^{-9}. This requirement can be converted into power by using the relation, $P_1 = N_P h\nu B$, where B is the bit rate and $h\nu$ is the photon energy. The received sensitivity defined $P_{rec} = (P_1 + P_0)/2 = P_1/2$ is given by [18]:

$$\tilde{P}_{rec} = N_p h\nu B / 2 = \tilde{N}_p h\nu \qquad (4.2)$$

where P_1 and P_0 are the power of bit 1 and bit 0, respectively, the quantity $\tilde{N}_P$ expresses the received sensitivity in terms of the average number of photons/bit and is related to N_P as $\tilde{N}_P = N_P / 2$, when 0 bit carry no energy.

IV.1 Loss Limited Communication Systems

The design of fiber optic communication systems requires understanding of the limitations imposed by fiber loss. Since the loss varies with the wavelength, the choice of operating wavelengths is a major design issue. There is a relationship between the wavelength employed, the type of transmission, and the achievable data rate. Both SMF and MMF can support several different wavelengths of light and can employ light- emitting diode (LED) or laser light source. The loss is lower at higher wavelengths allowing greater data rates over longer distance [25].

Now, consider the case of an optical transmitter that is capable of transmitting a maximum average power $\tilde{P}_{tr}$. If the signal is detected by a receiver that is required a minimum average power $\tilde{P}_{rec}$ at a bit rate B, then the maximum transmission distance is governed by [18]:

$$L_{\max} = (10/\alpha_f)\log_{10}\left(\tilde{P}_{tr} / \tilde{P}_{rec}\right) \qquad (4.3)$$

where α_f (dB/km) is the net loss of the fiber cable including splice and connector losses. The bit rate dependence of L arises from the linear dependence of P_{rec} on the bit rate.

V. EXPERIMENTAL MEASUREMENTS

The schematic block diagram of the experimental system is illustrated in figure 1.

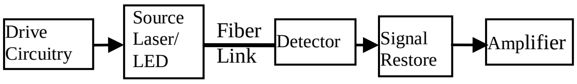

Figure 1: Schematic block diagram of fiber optic communication link

V.1 Determination Of Fiber Link Length And Fiber Attenuation Coefficient

Maximum transmission distance imposed by fiber attenuation coefficient can be practically determined by using ED-COM measuring instrumentation [26]. It is composed from Waveform Generator, LED transmitter, Laser Diode transmitter and optical receiver. The measurements have been carried out as follows:

From the oscilloscope measurements, the phase matched position between the two signals (i.e. output signals of the signal generator and via fiber reel at different frequencies) is found. It is worth to notice that at the phase match position all the signals transmitted via the optical fiber have the same phase irrespective of frequency and it matches the input phase of the signal directly from the signal generator at time zero. The fiber length is determined using the equation $L = ct_d / n$, where c is the velocity of light, n is the effective group refractive index and t_d is the total delay measured between signals.

The fiber attenuation coefficient, α, is obtained by the fiber attenuation over fiber reel/length (L) of fiber reel

V.2 Determination Of Attenuation Limited Link Lengths

Based on the measured data in subsection V.1, the attenuation limited link length, $L_{\max}$, is defined by:

$$\alpha L_{\max} = 10\log_{10}\frac{P_{in}}{P_{\min}} = 10\log 10\frac{A_{sig}}{A_{\min}} \qquad (5.1)$$

where P_{min} is the minimum detectable power (i.e. detector sensitivity), P_{in} is the detected power through 1 meter fiber patch cord, A_{min} is the noise signal generated by the isolated optical receiver which is measured as 21 mV bright band noise amplitude and it is equivalent to 4.2 mV_{rms} noise amplitude (voltage). Since, for reasonable detection at the receiver, SNR=12 is required for achieving the typical bit error rate (BER) of 10^{-9}, thus the minimum received signal amplitude can be found to be A_{min}=4.2$\times$12=50.4mV which is proportional to P_{min} and A_{sig}, the peak-to-peak amplitude, is proportional to the launched signal power P_{in}.

Finally, the maximum transmission distance imposed by fiber attenuation coefficient is determined by:

$$L_{\max} = \frac{1}{\alpha} 10\log_{10}\frac{A_{sig}}{A_{\min}} \qquad (5.2)$$

V.3 Determination Of Dispersion Limited Link Lengths

In the step response measurement the optical source is modulated by a square wave with a sharply rising edge and the 10-90% rise time, τ_o, of the transmitter/receiver combination is measured by inspection of the oscilloscope trace of the signal received via a short length of fiber. The measurement is repeated with the fiber reel connecting the transmitter to the receiver to obtain the 10-90% rise time, τ_s, of the entire system-the transmitter, receiver and the fiber. Since the BER(COM) unit produces one impulse for every bit sent, then 1 Mbits/s=1MHz. Consequently, when the received pulses are aligned with the transmitted ones, the bit rate displayed on the BER(COM) screen [26] will be equal to 1/(transit time through the fiber reel).

The maximum transmission distance imposed by fiber dispersion is done via measurement of bit rate distance product (BRL) which is based on measurement of fiber length with BER(COM). The fiber length is determined as follows: The optical path length in the fiber, $\Delta x = nL$, where n is the fiber refractive index (effective fiber group refractive index =1.497) and L is the fiber length. Since $\Delta x = c\Delta t$, where Δt, is the time taken for the light to pass through the fiber, then L is given by:

$$L = \frac{c\Delta t}{n} \quad (5.3)$$

The corner stone for the measurements is digitally modulate the LED transmitter. Using the oscilloscope, the pulse rise times (10% to 90%) can be measured, which can be used to determine BRL of the fiber reel. Knowing the BRL, the fiber link length imposed by fiber dispersion coefficient, i. e. determination of L_{max}, can be obtained and this done as follows:

The rise time of the complete system with fiber reel (τ_s) was displayed on the screen of the scope and is determined to be =17.9 ns. Then the fiber rise time (τ_f) is deduced from:

$$\tau_f = \sqrt{(\tau_s^2 + \tau_o^2)} \quad (5.4)$$

where τ_o is 9.2 ns

The bit rate-distance product can then be determined from the measurement of the fiber rise time (τ_f) by relating it to the output root mean squared pulse width, τ_R arising from a launched impulse, i.e. $\tau_R = 0.39\,\tau_f$. Therefore $\tau_R = 5.99\text{ns}$ and hence the maximum operating bit rate is given by:

$$B = \frac{0.25}{\tau_R}. \quad (5.5)$$

From which the maximum transmission distance imposed by fiber dispersion can be determined.

VI. RESULTS AND DISCUSSION

VI.1 Theoretical Results

The limitations of the maximum transmission distance due to fiber loss and dispersion have been evaluated using the following procedure:

In the case of fiber loss, we have calculated the initial value of the transmission distance (L_{LO}) using equations (4.2) and (4.3), then the maximum transmission distance (L_{max}) has been evaluated by using the relations, $L_{Li} = L_{LO} - 40\times i$ and $L_{Li} = L_{LO} - 25\times i$, for the single-mode at wavelength of 1550nm and 1300nm, respectively, whereas $L_{Li} = L_{LO} - 4\times i$ for multimode (step-index and graded index) at 850nm.

In the case of dispersion loss, we have calculated the initial value of the maximum transmission distance (L_{D0}) using equations (2.5.a) and (2.5.b), in both multimode step-index and graded index cases, respectively, and using equations (3.2) and (3.7), for single mode fiber at 1300 nm and 1550 nm, respectively. Then, the maximum allowed transmission distance has been calculated using the relations $L_{Di} = L_{DO}/10^i$ for MMF (step-index and graded index) at 850nm and SMF at 1300nm, whereas $L_{Di} = L_{DO}/100^i$ for single-mode fiber at 1550nm. The calculated results are represented in figures 2, 3 and 4.

Figure 2 shows the maximum allowable transmission distance as a function of bit rate due to the fiber loss, for all types of fibers. It is clear that the transmission distance slightly decreases from its initial value, L_{max}, as the bit rate increases. Figure 3 shows the maximum transmission distance limitation imposed by the dispersion of the fiber as a function of bit rate. As shown in the figure, the maximum transmission distance sharply decreases with increasing bit rate.

The combined effect of both the fiber loss and dispersion on the transmission distance as a function of bit rate is shown in figure 4. From the figure, it is clear that fiber loss is the dominant parameter that controller the transmission distance. However, as the bit rate increases, the transmission distance is controlled by fiber dispersion.

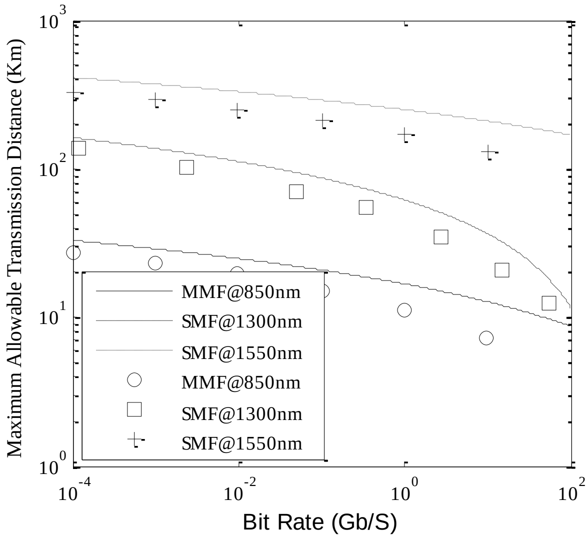

Figure 2: Maximum transmission distance imposed by the fiber loss versus bit rate. Lines theoretical results, symbols experimental results.

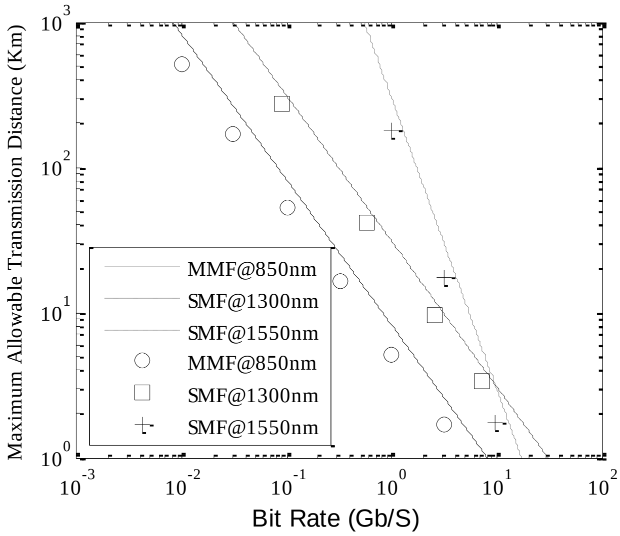

Figure 3: Maximum transmission distance imposed by the fiber dispersion versus bit rate. Lines theoretical results, symbols experimental results.

VI.2 Experimental Results

In this section we experimentally investigate the effect of fiber attenuation and fiber dispersion on the transmission distance and bit rate for the system shown in figure 1.

The obtained experimental results imposed by fiber attenuation and dispersion compared to theoretical results are shown in figures 2 and 3. The figures show that the experimental data is in good agreement with the theoretical data. The difference between experimental and theoretical results can be attributed to the sensitivity and accuracy of the instruments.

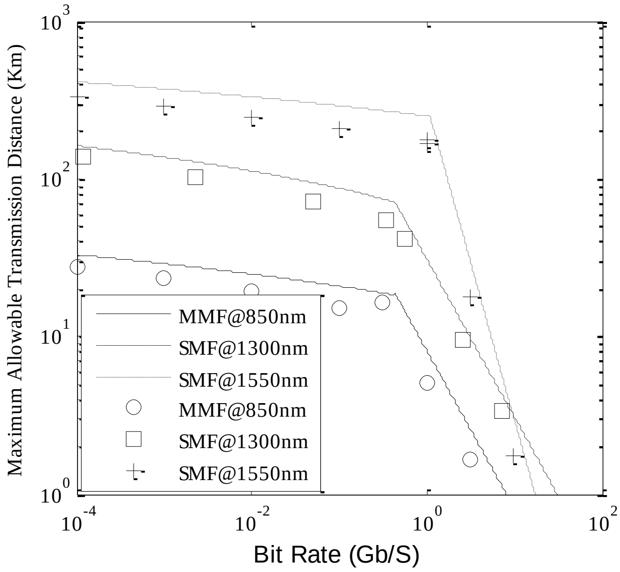

Figure 4: Maximum transmission distance versus bit rate imposed by the combined effects of both the fiber loss and dispersion. Lines theoretical results, symbols experimental results.

VII. CONCLUSION

An approach for computing the transmission limitations in optical networks has been presented. The effects of combined fiber loss and dispersion in light wave systems have been analyzed and investigated. An approach that allows to compute the maximum allowed transmission distance against bit rate has been provided. Thus, the system capacity can be determined using the product *BL*. It is found that fiber loss is the dominant factor that determine maximum allowable transmission distance at low bit rate. However, as the bit rate increases, fiber dispersion rather than fiber loss is the factor which determines the maximum allowable transmission distance. By comparing the three fibers under study, it is found that, 850nm fiber is the worst in terms of transmission distance, while the 1550nm has superiority over the 1330nm for bit rate <9.5Gb/s. However, for bit rate >9.5Gb/s the 1330nm fiber is better in terms of bit rate and transmission distance. An experimental work was implemented. The results showed that the experimental are quite close to the analytical results for low data rates. However, the discrepancy between practical and numerical results for high data rates can be attributed to the sensitivity and accuracy of the instruments available.

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