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Performance evaluation of FH-OCDMA in the presence of GVD and SPM

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Abstract: Performance analysis is carried out to evaluate Frequency-Hopping Optical Code Division Multiple Access (FH-OCDMA) in the presence of group velocity dispersion (GVD) and self-phase modulation (SPM). It is found that the system suffers higher power penalty as the dispersion increases. At a distance of 200-km the power penalty is reduced to 1 dB for DSF and to approximately 7 dB for SMF when SPM is included. The SMF without SPM suffers the highest power penalty of 6.7 dB at 100-km and 9.5 dB at 200-km.

Keywords: Frequency-Hopping (FH), Optical Code Division Multiple Access (OCDMA), GVD, and SPM.

Classification: Photonics devices, circuits, and systems

References

[1] Habib Fathallah, Leslie A. Rusch, and Sophoe LaRochelle, "Passive optical fast frequency-hop CDMA communications system," *J. Lightwave Technol.*, vol. 17, no. 3, 1999.

[2] Chao Zuo, "The Impact of Group Velocity on Frequency-Hopping Optical Code Division Multiple Access System," *J. Lightwave Technol.*, vol. 19, no. 10, Oct. 2001.

[3] J. A. Salehi, "Code division multiple-access techniques in optical fiber networks – part I: Fundamental principles," *IEEE Trans. Commun.*, vol. 37, pp. 824–833, Aug. 1989.

[4] H. P. Sardesai, C. C. Chang, and A. M. Weiner, "A femtosecond code-division multiple-access communication systems test bed," *J. Lightwave Technol.*, vol. 16, pp. 1953–1964, Nov. 1998.

[5] H. M. H. Shalaby, "Direct detection optical overlapping PPM-CDMA communication systems with double optical hardlimiters," *J. Lightwave Technol.*, vol. 16, pp. 1953–1964, Nov. 1998.

[6] S. P. Majumder, Afreen Azhari, and F. M. Abbou, "Impact of fiber chromatic dispersion on the BER performance of an optical CDMA IM/DD transmission system," *IEEE Photon. Technol. Lett.*, vol. 17, no. 6, 2005.

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1 Introduction

The development of the optical fiber communication technology has developed rapidly to achieve larger transmission capacity and longer transmission distance. The demand on the increasing system and network capacity is expected to remain as more bandwidth-needing technologies like videoconference and real-time image transmission emerge. Thus, fulfill the capacity increasing requirement, new devices and technologies are in great need. In wireless communication systems, Code Division Multiple Access (CDMA) allows multiple users to access network simultaneously using unique codes. CDMA offers many advantages over other multiplexing technologies for local area networks (LANs), including high capacity, asynchronous and decentralized operation. Thus, CDMA communications is a potential candidate for the upcoming generation of optical interconnection between a high numbers of active users in a high bit rate LAN. This success of CDMA has inspired the use of its technologies for asynchronous optical network – Optical CDMA (OCDMA). Research on OCDMA has focused on direct time spread OCDMA [3], spectral encoding-decoding on direct time spread OCDMA [4], pulse position modulation OCDMA [5] and frequency hopping (FH) OCDMA [1]. The BER performance of Frequency-Hopping Optical Code Division Multiple Access System without considering the effect of SPM has been reported [2]. Dispersion degrades the system performance due to increased inter-chip interference and reduced received optical power. In this paper, theoretical analysis is presented to evaluate BER of a FH-OCDMA system in present of the combined effect of dispersion and SPM. Section 2 contains the theoretical analysis and the analysis of dispersion and nonlinear effect caused by SPM in a fiber channel system. Section 3 discusses the effects of dispersion and SPM in a transmission system. Finally, Section 4 summarizes and concludes this paper.

2 Theoretical Analysis

Let's consider a typical OCDMA communications network with transmitter and receiver pairs where K users share the same optical medium in a star architecture. Each information bit from user k is encoded onto an address sequence as:

$$C_k(t,f) = \sum_{i=1}^{q}\sum_{j=1}^{N} c[j,i]\psi(t - jT_c, f - f_i) \qquad (1)$$

where N is the length of the code, q is the number of available frequencies, $c[j,i]$ is either 1 or 0 depending on whether the i^{th} frequency is used in the j^{th} time slot, T_c is the chip duration, $T = NT_c$ is the bit duration and the chip signal $\psi(t,f)$ is the optical pulse with different frequencies. In an FH-OCDMA system, each information bit from a given user is encoded onto a hop pattern. Thus, the j^{th} pulse is modulated with frequency-offset f_j about the carrier frequency f_c:

$$f_j = h(j)\frac{B}{q} \quad j = 1, 2, \ldots, N \text{ and } 1 \le h(j) \le q \qquad (2)$$

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where B is the available frequency bandwidth, $h(j)$ is the placement operator (FH pattern) and q is the number of available frequencies. The placement operator is a sequence of N ordered integers determining the placement if frequencies in the N available time slots. Each user selects a set of N frequencies from a set of q available frequencies. In FH system, chip pulses are generated in different and disjoint frequency sub-bands, which mean pulses with different colors. Each transmitter broadcasts its encoded signal to all the receivers in the network. At the receiver, the received signal is a sum of all the active users' transmitted signal.

$$r(t) = \sum_{k=1}^{K} b_k c_k(t - \tau_k) \tag{3}$$

where $b_k \in \{0, 1\}$ and $0 \leq \tau_k \leq \mathrm{T}_c$, for $k = 1, 2, 3, \ldots, K$, are the k^{th} user's information bit and time delay respectively. A matched filter is used to decode back the desired signal. A selected user's code is chosen to satisfy the following three fundamental conditions. Firstly, the peak of the auto-correlation function should be maximized for each code. Secondly, the side lobes of auto-correlation should be minimized and finally, the cross-correlation function of each pairs of sequences should be minimized.

In order to investigate the combined effect of dispersion and SPM, the Split Step Fourier Method (SSFM) is used to simulate the pulse according to the following equation:

$$\frac{\partial A}{\partial z} = (\hat{D} + \hat{N})A \tag{4}$$

where

$$\hat{D} = -\frac{\alpha}{2} - \frac{i}{2}\beta_2 \frac{\partial^2}{\partial T^2} + \frac{1}{6}\beta_3 \frac{\partial^3}{\partial T^3}, \text{ and } \hat{N} = i\gamma(|A|^2) \tag{5}$$

where $\hat{D}$ is D the differential operator that includes dispersion and attenuation in fiber while $\hat{N}$ is a nonlinear operator that contains nonlinearities in fiber. A is the signal amplitude, α is the fiber attenuation coefficient, β_2 is the dispersion parameter, β_3 is the second order dispersion, and γ is the nonlinear parameter. Let's say a sum of K-1 independent random variables available in the system, its variance can be approximated as:

$$\sigma^2 = \frac{(K-1)(\sigma^2)^2}{N} \tag{6}$$

where $\sigma^2 = \sigma^2_{m,p}$ is the mean value of the variance of the cross-correlation between each pair of codes

$$\sigma^2_{m,p} = \frac{1}{2L-1} \sum_{s=-L+1}^{L-1} \left(R_{m,p}(s) - \overline{R_{m,p}} \right)^2 \tag{7}$$

where L is the length of the bit sequence, $R_{m,p}$ is the cross-correlation between codes m and p and $\overline{R}_{m,p}$ is the average value of $R_{m,p}$. The mean can be similarly expressed as:

$$\mu = \frac{RP_r}{2} \overline{R}_{m,p} \tag{8}$$

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where R is the responsivity of photo-diode and P_r is the received power which defined as $P_r = R_{m,p}(0)$. The signal to interference ratio can be expressed as:

$$SIR = \frac{\mu^2}{\sigma^2_{MAI}} \tag{9}$$

The probability of error for equiprobable data is given as:

$$P_e = Q\left(\frac{\mu}{\sqrt{(K-1)\sigma^2}}\right) \tag{10}$$

3 Results and Discussions

Following the theoretical analysis presented in section 2, the BER performance of a FH-OCDMA in the presence of dispersion and SPM is evaluated using simulation. In order to valuate the BER, the FH-code is encoded using bit sequences of length $2^9 - 1$ bits with a fiber length of 100-km. The 7-chip sequence used in this simulation is [1 1 1 0 0 1 0]. Each chip represents a Gaussian pulse and modulated with frequency corresponding to the frequency hop pattern. The dispersion coefficient D is ranging from 1 to 16 ps/nm/km, and the operating wavelength is 1550-nm.

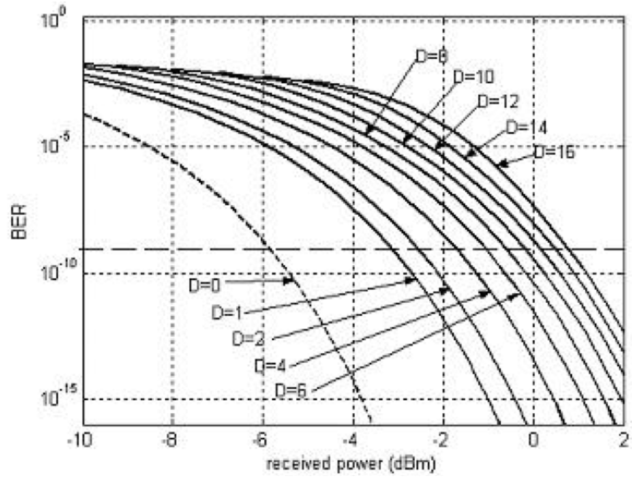

Fig. 1. BER versus Received Power (dBm)

Figure 1 shows the curves of bit-error rate (BER) versus received power with varying fiber dispersion coefficient. It is evident that high value of dispersion coefficient results in a high BER and the power requirement increases as the dispersion coefficient increases.

Further, a comparison of FH-OCDMA using SMF and DSF with and without self-phase modulation with $\gamma = 2W^{-1}\,km^{-1}$ is depicted in Fig. 2.

It can be observed that for both cases the BER has been improved when SPM effect is taken in consideration due to the soliton effect, which results from the balance between dispersion and SPM. Figure 3 shows the Power Penalty vs. Distance for DSF and SMF for various configurations with varying fiber length.

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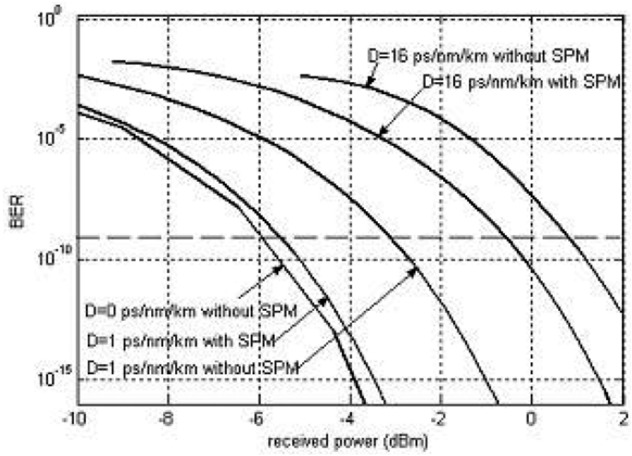

Fig. 2. Comparison of BER versus Received Power (dBm)

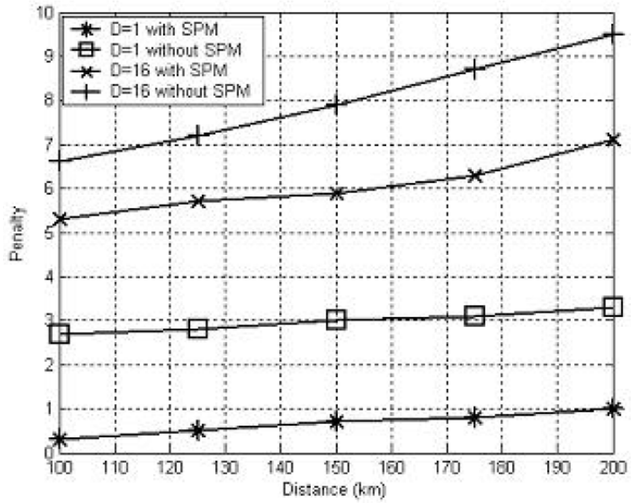

Fig. 3. Comparison of power penalty for the system with/without SPM corresponding to different fiber length.

It can be observed that the power penalty is slowly increasing with respect to the fiber length for DSF and approximately exponential increasing with SMF configuration. FH-OCDMA with SPM and DSF has the lowest power penalty as compared to the other cases. At a distance of 200-km the power penalty is reduced to 1 dB for DSF and to approximately 7 dB for SMF with SPM. The single mode fiber ($D = 16$ ps/nm/km) without SPM suffers the highest power penalty with 6.7 dB at 100-km and to 9.5 dB at 200-km.

4 Conclusions

Split-Step Fourier-Method (SSFM) was used as a numerical model to study the combined effect of dispersion and SPM on FH-OCDMA. The SMF without SPM suffers the highest power penalty of 6.7 dB at 100-km and 9.5 dB at 200-km. However, when SPM is included, the power penalty is reduced to 1 dB for DSF at a distance of 200-km and to approximately 7 dB for SMF. It is evident that the system suffers a higher power penalty as the dispersion

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coefficient is increased and the soliton effect can be used in FH-OCDMA systems to balance the broadening induced by dispersion.

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