第33卷第10期 光 子 学 报 Vol. 33 No. 10
2004年10月 ACTA PHOTONICA SINICA October 2004

Performance Improvement for Optical Fast Frequency-hopping CDMA System Employing Turbo Code*

Ji Jianhua, Yang Shuwen, Ma Junxian, Xu Ming
Advanced Technology Research Center of Shenzhen University, Shenzhen 518060

Abstract Upper bounds on the bit error rate for turbo-coded optical fast frequency-hopping CDMA networks using binary PPM modulation is educed, considering multi-access interference, the effect of dispersion and optical beat noise. Analysis results show that turbo-coded FFH OCDMA systems have much better performance than uncoded systems.

Keywords Fast frequency-hopping optical code-division multiple-access(FFH OCDMA) ;Turbo code; Binary pulse position modulation(BPPM);Bit error rate(BER)
CLCN TN929.11 **Document Code** A

0 Introduction

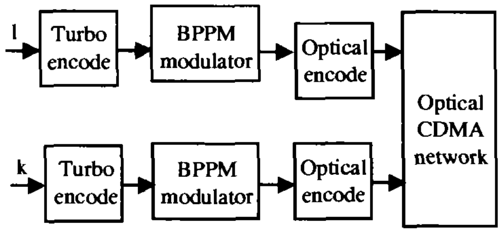
Optical fast frequency-hopping code-division multiple-access systems (FFH OCDMA) have recently been proposed as a candidate for optical local area networks(LANs)[1]. In this scheme, FBGs are coding devices, which slice the spectrum of the incoming pulse to reflect. The output of devices is a train of pulses the frequencies of which are hopping in time. It has advantage of coding optically and passively.

Recently, turbo codes have attracted much attention because of their astonishing error performance and their reasonable decoding complexity, both in wireless CDMA systems[2,3] and optical CDMA systems[4,5]. In [4,5], upper bounds on the BER for turbo-coded one-dimensional optical CDMA systems using pulse position modulation (PPM) is obtained. However, For FFH OCDMA systems (two-dimensional optical CDMA), the effect of dispersion and optical beat noise is very serious, and BER performance has not been analyzed.

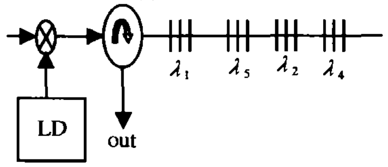
In this paper, after considering the effect of multi-access interference(MAI), dispersion and optical beat noise, the upper bonds on BER for turbo-coded FFH OCDMA using BPPM is obtained. Compared with uncoded FFH OCDMA, turbo-coded FFH OCDMA has much better BER performance.

1 System model

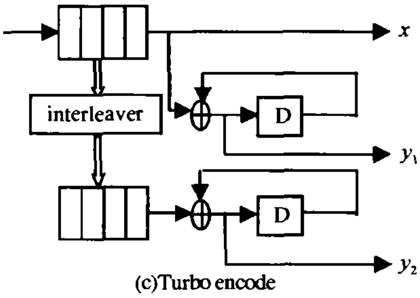
Fig. 1 is the system model of turbo-coded FFH OCDMA using BPPM. Each data bit is coded into two slots(slot 1 and slot 2) by BPPM. For data bit“0”, pulse signal is modulated in slot 1. For data bit“1”, pulse signal is modulated in slot 2. After optical coded by FBGs, optical pulse is transmitted by optical network which is composed of fibers and optical coupler. At the receiver, optical pulse is decoded by FBGs, then converted into electrical signal. By comparing the outputs of slot 1 and slot 2, BPPM decoder can judge “0” or“1”。 In the end, Turbo decoder may recover the data bit.



(a)Transmitter



(b)Optical encode



(c)Turbo encode

Fig. 1 Turbo-coded FFH OCDMA system based on BPPM modulation

2 Analysis of BER

The one-coincidence sequences discussed and constructed in [6] possess the following properties:

1) All of the sequences are of the same length.

2) All of the sequences are nonrepeating, that is, each frequency is used at most once within the sequence period. This property faciliates a simple

---

*Supported by National Natural Science Foundation of China (No.60132040)
Tel:0755-26536153 Email:jh_ji@sohu.com
Received date:2003-09-16

synchronization scheme.

3) The maximum number of hits between any pair of sequences for any time shift equals one.

4) Any two adjacent frequencies in any sequences have absolute difference larger than $d \geqslant 0$ for some fixed integer d.

Let q frequencies be available and $N = q - 2d - 1$, we can construct a set of q one-coincidence sequences with code length N. The probability of coincidence for any two sequences is

$$P = \frac{N(N-1)/N}{q-1} = \frac{N-1}{q-1} \tag{1}$$

Using BPPM, the probability of coincidence in slot 1 (or slot 2) is

$$P_1 = \frac{N-1}{2(q-1)} \tag{2}$$

For all $K-1$ interference users, there are n users coincided in slot 1, j users coincided in slot 2. The output of slot 1 and slot 2 are Y_1 and Y_2 respectively. We assume the data bit of one designed user is "0".

Considering the effect of MAI and optical beat noise, the received signal can be described as Gauss-model[7,8]. In [9], we have analyzed the effect of dispersion in FFH OCDMA, and it can be represented as an attenuation factor α of signal energy. Therefore, after taking into account the effect of MAI, optical beat noise and dispersion, output Y_1 can be expressed as

$$\begin{aligned} \mu_1 &= \alpha N + n \\ \sigma_1^2 &= 2n + 2C_n^2/N \end{aligned} \tag{3}$$

Output Y_2 can be expressed as

$$\begin{aligned} \mu_2 &= j \\ \sigma_2^2 &= 2C_j^2/N \end{aligned} \tag{4}$$

Therefore, BER for uncoded FFH OCDMA is

$$p_b = \sum_{n=0}^{K-1} \sum_{j=0}^{K-1-n} C_{K-1}^{n+j} \left[\frac{N-1}{2(q-1)}\right]^{n+j} \cdot \left[1 - \frac{N-1}{2(q-1)}\right]^{K-1-n-j} \times \left\{ \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi\sigma_1^2}} e^{-(x-\mu_1)^2/2\sigma_1^2} \times \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi\sigma_2^2}} e^{-(y-\mu_2)^2/2\sigma_2^2} \mathrm{d}x\mathrm{d}y \right\} \tag{5}$$

For turbo-coded system, BER can be expressed as[2]

$$P_{bt} = \sum_{i=1}^{L} \sum_{d_1=0}^{L} \sum_{d_2=0}^{L} \frac{i}{L} A(i, d_1, d_2) P_e(i, d_1, d_2) \tag{6}$$

Where L is the length of interleaver, $A(i, d_1, d_2)$ is the number of codes with input Hamming weight i and output Hamming weight d_1 and d_2. Under uniform interleaver[2]

$$A(i, d_1, d_2) = \sum_{d_1=0}^{L} \sum_{d_2=0}^{L} \frac{g_1(L, i, d_1) \times g_2(L, i, d_2)}{C_L^i} \tag{7}$$

$g_1(L, i, d_1)$ and $g_2(L, i, d_2)$ denote the number of paths with length L, input Hamming weight i and output Hamming weight d_1 and d_2 for encoder 1 and encoder 2 respectively.

$P_e(i, d_1, d_2)$ is BER for code which has input Hamming weight i and output Hamming weight d_1 and d_2, we define d is the total output Hamming weight, i. e, $d = i + d_1 + d_2$.

For turbo-coded FFH OCDMA, output Y_1 is

$$\begin{aligned} \mu_1 &= d(\alpha N + n) \\ \sigma_1^2 &= d(2n + 2C_n^2/N) \end{aligned} \tag{8}$$

output Y_2 is

$$\begin{aligned} \mu_2 &= dj \\ \sigma_2^2 &= 2dC_j^2/N \end{aligned} \tag{9}$$

Therefore, $p_e(i, d_1, d_2)$ can be

$$p_e(i, d_1, d_2) = \sum_{n=0}^{K-1} \sum_{j=0}^{K-1-n} \left\{ C_{K-1}^{n+j} \left[\frac{N-1}{2(q-1)}\right]^{n+j} \cdot \left[1 - \frac{N-1}{2(q-1)}\right]^{(K-1-n-j)} \right\}^d \times \left\{ \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi\sigma_1^2}} e^{-(x-\mu_1)^2/2\sigma_1^2} \cdot \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi\sigma_2^2}} e^{-(y-\mu_2)^2/2\sigma_2^2} \mathrm{d}x\mathrm{d}y \right\} \tag{10}$$

Combined (7), (10) with (6), upper bonds on BER for turbo-coded FFH OCDMA can be obtained after considering the effect of MAI, dispersion and beat noise.

Fig. 2 is BER performance of turbo-coded FFH OCDMA based on BPPM modulation, here $\alpha = 0.88$, one-coincidence sequence is $q = 29$, $N = 18$, $d = 5$. As it shows, the BER performance of turbo-coded FFH OCDMA is much better than uncoded FFH OCDMA.

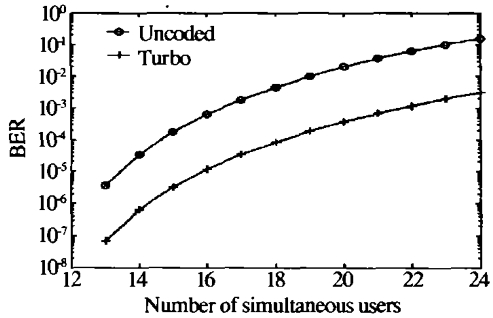


Fig. 2 BER performance of FFH OCDMA based on BPPM modulation

3 Conclusion

Upper bounds on the BER for turbo-coded FFH OCDMA using binary PPM modulation is obtained, taking into account the effect of MAI, dispersion and optical beat noise. Analysis results show that Turbo-coded FFH OCDMA systems have much better performance than uncoded systems. In other words, Turbo-coded FFH OCDMA systems can accommodate more simultaneous users.

References

1 Fathallah H, Leslie A R, Sophie L. Passive optical fast frequency-hop CDMA communications system. *Journal of Lightwave Technology*, 1999, **17**(3): 397 ~ 405

2 Sergio B, Guido M. Unveiling turbo codes: some results on parallel concatenated coding schemes. *IEEE Transaction on Information Theory*, 1996, **42**(2):409 ~ 428

3 Claude B, Alain G. Near optimum error correcting coding and decoding: turbo-Codes. *IEEE Transaction on Communications*, 1996, **44**(10):1261 ~ 1271

4 Jin Y K, Poor H V. Turbo-coded optical direct-detection CDMA systems with PPM modulation. *Journal of Lightwave Technology*, 2001, **19**(3): 312 ~ 323

5 Ohtsuki T, Kahn J M. BER performance of turbo-coded PPM CDMA systems on optical fiber. *Journal of Lightwave Technology*, 2001, **18**(12): 1776 ~ 1784

6 Li Bin. One-coincidence sequence with specified distance between adjacent symbols for frequency-hopping multiple access. *IEEE Transactions on Communications*, 1997, **45**(4):408 ~ 410

7 Tancevski L, Rusch L A. Impact of the Beat Noise on the Performance of 2-D Optical CDMA Systems. *IEEE Communications Letters*, 2000, **4**(8): 264 ~ 266

8 Ji Jianhua, Fan Ge. Reduction of optical beat noise in fast frequency-hopping optical CDMA systems by truncated one-coincidence sequence. *Acta Photonica Sinica*, 2003, **32**(3): 301 ~ 303

9 Ji Jianhua, Fan Ge. Reduction of the impact of chromatic dispersion in optical fast frequency-hopping CDMA networks by BCH channel coding. *Acta Photonica Sinica*, 2002, **31**(12):1475 ~ 1478

Turbo码对快跳频光码分多址系统性能的改善

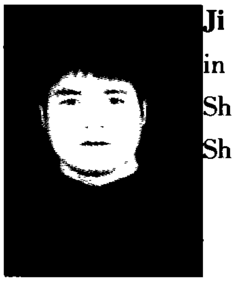
吉建华 杨淑雯 马君显 徐 铭

（深圳大学新技术研究中心，深圳 518060）

收稿日期:2003-09-16

摘 要 在考虑多用户干扰、色散效应和差拍噪声的情况下，分析了Turbo码对二进制脉冲位置调制(BPPM)的快跳频光码分多址(FFH OCDMA)系统性能的影响．在均匀交织器的情况下，用Turbo码的条件重量枚举函数得到了该系统的误码率的上界．数值模拟表明，Turbo码对FFH OCDMA系统的误码率性能有明显的改善，并且随着用户数的提高，Turbo码对误码率的改善程度也随之提高．也就是说，在一定的误码率性能要求下，Turbo编码的FFH OCDMA系统增加了同时使用的用户数．

关键词 快跳频光码分多址；Turbo码；二进制脉冲位置调制；误码率



Ji Jianhua received the B. S. degree in Southeast University in 1991, received the M. S. degree in University of Shanghai for Science and Technology in 2000, and received the Ph. D. degree in Shanghai Jiaotong University. Now he works in the Advanced Technology Research Centre of Shenzhen University. His research interests include OCDMA and WDM networks.