INTERFERENCE REDUCTION IN SYNCHRONOUS FIBER-OPTIC PPM–CDMA SYSTEMS

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ABSTRACT: *A pulse-position modulation (PPM) optical CDMA system with interference estimation and cancellation is proposed. Multiuser interference is estimated with the aid of modified prime code sequence properties. A comparison between the bit-error rate (BER) of both the proposed system and the system without cancellation reveals that the former system improves the BER performance significantly.* Microwave Opt Technol Lett 30: 202–205, 2001.

Key words: *optical communications; fiber-optic systems; interference reduction*

1. INTRODUCTION

The performance of an optical CDMA is largely reduced by the presence of multiuser interference (MUI). Much work is focused on reducing the MUI so that more users can be accommodated into the system [1–6]. Synchronous CDMA systems have been shown to exhibit some advantages over their asynchronous counterparts [6]. For example, a synchronous CDMA system can accommodate a greater number of simultaneous users than an asynchronous CDMA system for a given bit-error rate (BER). It has been shown that, by using interference cancellation, we can reduce MUI significantly [1, 3, 4, 5]. A cancellation technique, which is based on PPM signaling and which improves the overall system performance, has been reported in [1]. However, the disadvantages of this system are: 1) power splitting loss, 2) system complexity, and 3) a long signature sequence.

Modified prime code sequences are well used in many interference cancellation systems [1, 5]. This is because they exhibit what is called the grouping property, where all of the sequences in this code are classified into different groups. Sequences from the same group have complete orthogonality, while those from different groups have incomplete orthogonality, with a constant cross correlation equal to 1. Optical CDMA systems suffer from multiple-user interference due to the incomplete orthogonality of its codes. Several proposals to minimize this interference have appeared in literature. For example, Shalaby [1] has proposed an interference cancellation for OOK–CDMA systems by keeping one code in each group of the modified prime code sequences unallocated to any user. This unused code can be utilized to provide an estimate to the interference, whose effect can, in turn, be removed from the received signal. The aim of this letter is to extend the method introduced in [5] for the optical PPM–CDMA systems, and to analyze its overall performance. In the analysis, we have used Manchester codes in signaling the transmitted data for further improvement of the bit-error probability performance.

2. OPTICAL PPM–CDMA SYSTEM DESCRIPTION

The transmitter for an optical PPM–CDMA communication system is shown in Figure 1. It consists of N simultaneous users, where each user transmits M-ary continuous data symbols. The output symbol of the kth information source modulates the position of a laser pulse to form the PPM signal. The signal is then multiplied by the prime code sequence of the kth user. The output waveform is finally transmitted over the optical channel. To further improve the bit-error probability, we have used the Manchester coding scheme as follows. The optical pulses for the spreading sequences in the first $(p+1)/2$ groups of users (out of p groups) are signaled in the first half-chip intervals [see Fig. 1(a)], while the remaining $(p-1)/2$ groups of users are using the second half-chip intervals. The code sequences used in our analysis are the modified prime code sequences where, for any given prime number p, there are p^2 code sequences that can be generated. Each code sequence has a weight p and a length p^2. The codes are divided into p groups, where each consists of p different codes. The cross correlation (C_{mn}) between code m and code n, $m, n \in \{1, 2, \ldots, p^2\}$, is given by

$$C_{mn} = \begin{cases} p, & \text{if } m = n \\ 0, & \text{if } m \text{ and } n \text{ share the same group and } m \neq n \\ 1, & \text{if } m \text{ and } n \text{ are from different groups.} \end{cases} \tag{1}$$

3. OPTICAL PPM–CDMA WITH INTERFERENCE ESTIMATION

The proposed interference estimation and cancellation system for which we have analyzed the BER performance in this section is shown in Figure 2. In this system, there are two branches for each receiver. The signal in the upper branch consists of the desired signal and interference, whereas the lower branch contains only the estimated interference. Subtracting the signal in the upper branch from the interference in the lower branch before passing it to the decision mechanism can reduce the effect of this interference. To provide an estimate of the interference, we apply a similar approach as that used in OOK–CDMA [5]. That is, the last code in each group is not assigned to any user, and is reserved for multiple-user interference (MUI) estimation at the receiving end. The total number of subscribers is thus limited to $p^2 - p$. Out of this number, we assume that there are N active (simultaneous) users, and the remaining $p^2 - p - N$ users are idling. Without loss of generality, let us assume that user 1 is the desired user and the random variable T is the number of active users in the first group. The probability distribution of the random variable T given that user 1 is active for any $t \in \{t_{\min}, t_{\min+1}, \ldots, t_{\max}\}$, where $t_{\min} = \max\{1, N + 2p - p^2 - 1\}$ and $t_{\max} = \min\{N, p-1\}$, can be expressed as [5]

$$P_T(t) = \frac{\binom{p^2 - 2p + 1}{N - t}\binom{p - 2}{t - 1}}{\binom{p^2 - p - 1}{N - 1}}. \tag{2}$$

We define another random variable R for the number of active users from group 2 up to group $(p+1)/2$. The probability of this random variable for any $r \in \{r_{\min}, r_{\min+1}, \ldots, r_{\max}\}$, where $r_{\min} = \max\{0, N - t - (p^2 - 2p + 1)/2\}$ and $r_{\max} = \min\{(p^2 - 2p + 1)/2, N - t\}$ given that

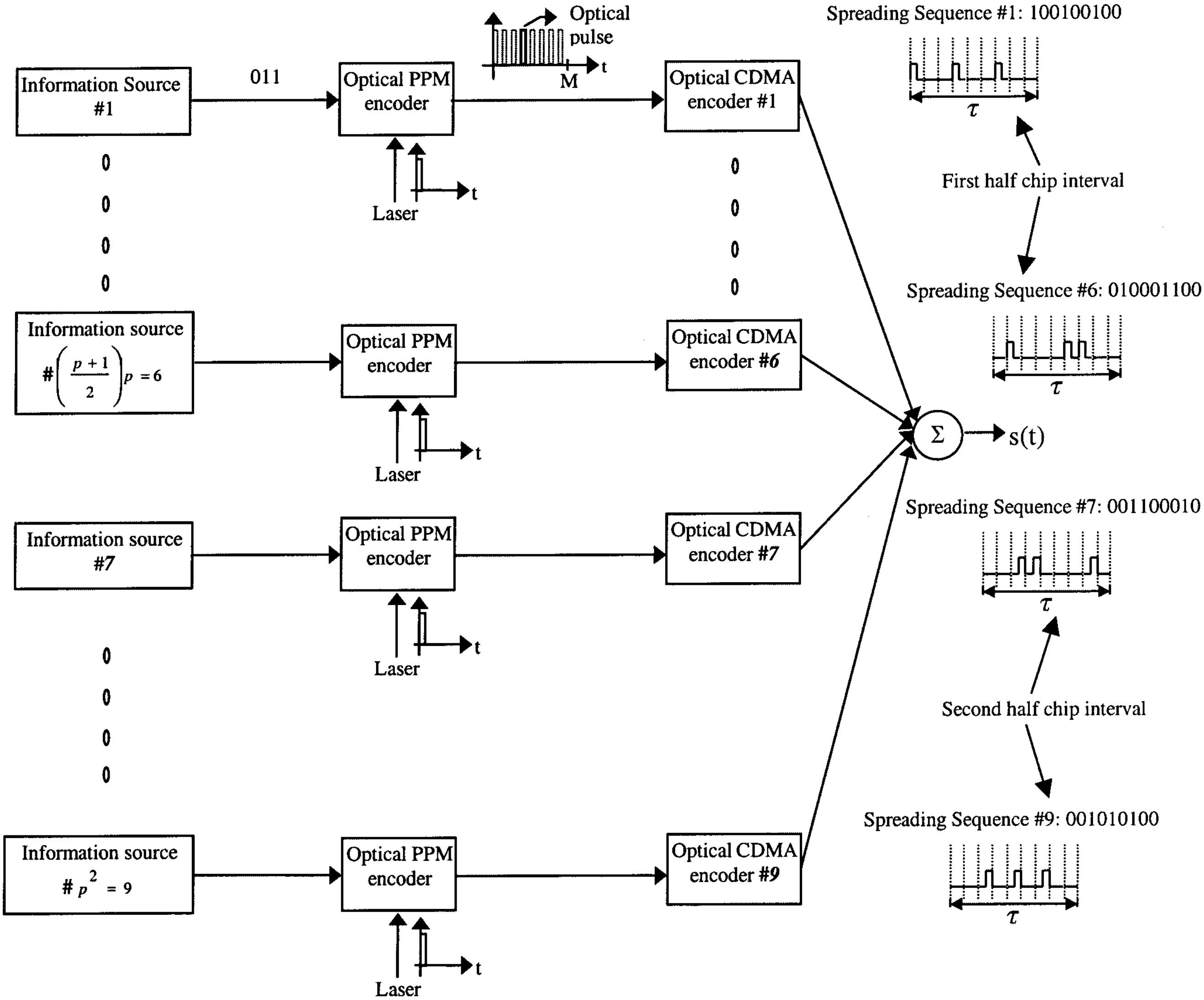

Figure 1 Optical PPM–CDMA transmitter system with alternate Manchester coding (8-ary PPM CDMA, with prime code sequence length of 9 ($p = 3$); information source #1 sending symbol 4 (011 bits), and the prime code sequence of source #1 is 100 010 001)

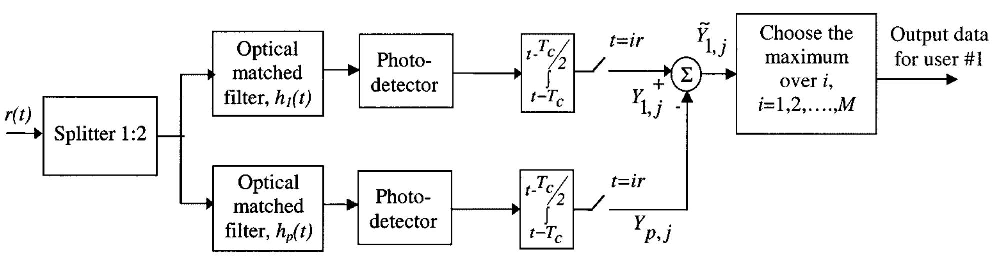

Figure 2 Direct-detection optical PPM–CDMA system model with interference cancellation

$T = t$, can be expressed as

$$P_{R|T}(r|t) = \frac{\binom{(p^2-2p+1)/2}{r}\binom{(p^2-2p+1)/2}{N-t-r}}{\binom{p^2-2p+1}{N-t}}. \quad (3)$$

We define the interference random vector $\mathbf{l}$ by

$$\mathbf{l} = \sum_{n=p+1}^{[(p+1)/2]p} \mathbf{V}_n \quad (4)$$

where $\mathbf{V}_n$ is a column vector of size M for user n. If this user sends symbol $i \in \{0, 1, \ldots, M-1\}$, then all entries in $\mathbf{V}_n$ will be equal to zero, except for the ith entry. The average photon count due to the interference $\mathbf{l}$ is the same for all users in one group. Given $T = t$ and $R = r$, it is easy to check that $\mathbf{l}$ is a multinomial random vector with probability

$$P_{\mathbf{l}|T,R}(l_0, l_1, \ldots, l_{M-1}|t, r) = \frac{1}{M^r} \cdot \frac{r!}{l_0! l_1! \ldots l_{M-1}!} \quad (5)$$

where $\sum_{i=0}^{M-1} l_i = r$. To reduce the interference, we construct the vector $\tilde{\mathbf{Y}}_1$ as follows:

$$\tilde{\mathbf{Y}}_1 = \mathbf{Y}_1 - \mathbf{Y}_p. \quad (6)$$

The decision to select the received symbol by user 1 is as follows. Symbol i is declared to be the correct one if $\tilde{\mathbf{Y}}_{1,i} > \tilde{\mathbf{Y}}_{1,j}$ for every $j \neq i$. An upper bound on the bit-error probability can be derived as follows:

$$P_b = \frac{M}{2(M-1)} \sum_{t=t_{\min}}^{t_{\max}} \sum_{r=r_{\min}}^{r_{\max}} P_E^{t,r} P_T(t) P_{R|T}(r|t) \quad (7)$$

where

$$P_E^{t,r} \le (M-1) \sum_{l_1=0}^{r} \binom{r}{l_1} \left(\frac{1}{M}\right)^{l_1} \left(1 - \frac{1}{M}\right)^{r-l_1} \times \sum_{l_0=0}^{r-l_1} \binom{r-l_1}{l_0} \left(\frac{1}{M-1}\right)^{l_0} \left(1 - \frac{1}{M-1}\right)^{r-l_0-l_1} \times \exp\left[-Q \frac{p^2}{4(p + l_0 + l_1)}\right]. \quad (8)$$

It should be noticed that, as $Q \to \infty$, $P_E^{t,r} = 0$.

4. NUMERICAL RESULTS

In this section, we compare the performance of the following two synchronous optical PPM–CDMA systems:

1. with interference cancellation and Manchester codes, and
2. without interference cancellation [1].

Figure 3 show variations of the bit-error probability (BEP), with μ defined as the average received photons per nat for the two optical PPM–CDMA systems with various values of M. Both Q and μ are related by the equation $\mu = Qp/\ln M$. The prime number p and the number of simultaneous users N are set as $p = 13$, $N = 156$ (full load condition). It can be seen that the system performance under the Poisson shot noise model for the receiver photodetector in case 1) is much better than that of case 2) for moderate values of μ and M. The improvement is more apparent as μ increases. In fact, the bit-error probability for systems with interference cancellation reduces to zero as μ approaches infinity. However, when both M and μ are too small, the system without cancellation performs slightly better than the other two systems. Our numerical results show that, as the value of symbol M increases, the performance of the case 1) system improves significantly. The results clearly show that using Manchester codes improves the system performance; however, it increases the system bandwidth.

In Figure 4, for cases both with and without cancellation systems, we have shown variations of the BEP upper bounds with the number of users for $p = 13$ and $M = 8$. In the analysis, we have used $\mu = 100$ for systems 1) and $\mu = \infty$ for the system 2). It is obvious that a very large number of simultaneous users can be accommodated with relatively low bit-error rates for the systems with interference cancellation as long as μ and/or M are large enough. However, this is not true for the system without cancellation, as shown in the numerical results. The improvement is more significant as the number of simultaneous users N increases.

5. CONCLUSION

In this letter, a synchronous optical PPM–CDMA system with interference estimation and cancellation has been proposed. The correlation properties of the prime code sequence have been used to provide an estimation on the multiuser. This estimated interference has been subtracted from the received signal after photodetection. In addition, we have used Manchester codes to further improve the overall system bit-error rate performance. We have compared the bit-error probabilities of the proposed systems with each other and

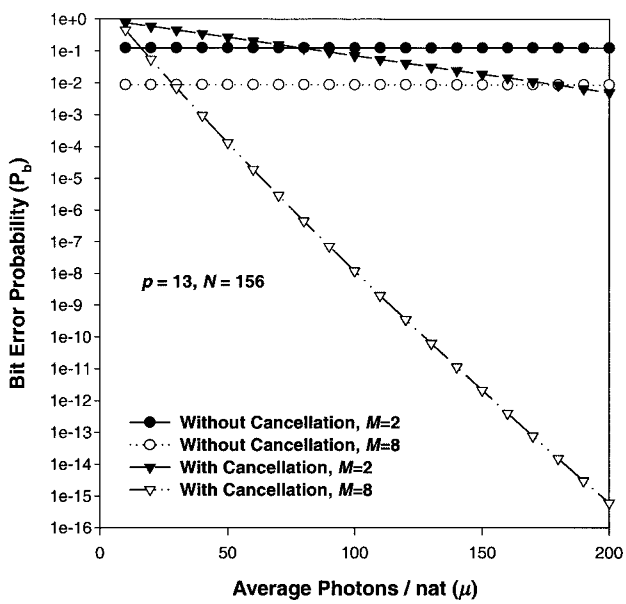

Figure 3 Comparison between lower bounds on the BER of PPM–CDMA systems without cancellation [1] and upper bounds on the BER of PPM–CDMA systems with cancellation (with and without Manchester codes) for $p = 13$ and $N = 156$ (full load condition). The lower bounds are evaluated at $\mu = \infty$

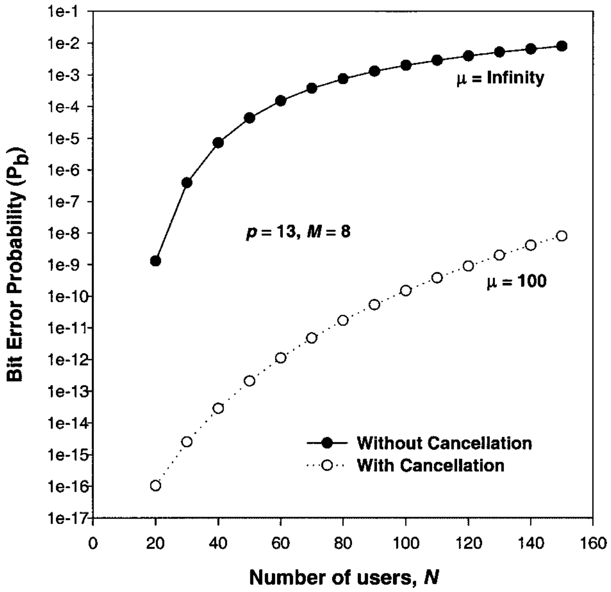

Figure 4 PPM−CDMA BER variations versus the number of simultaneous users for $p = 13$ and $M = 8$. For the system without cancellation [1], a lower bound is evaluated at $\mu = \infty$. For the system with cancellation, an upper bound is evaluated at $\mu = 100$

with that of the PPM−CDMA system without interference. Our results reveal that the bit-error rates have considerably improved with the adoption of the aforementioned techniques. We have also proved theoretically that the bit-error probability of the proposed systems approaches zero as the average photon count increases to infinity. That is, the error probability floors (which distinguish this types of system) can be completely removed.

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A COMPARISON OF DUAL-BAND SPUR-LINE PRINTED ANTENNAS FOR HANDHELD TERMINALS

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ABSTRACT: *Recent breakthroughs in mobile phone technology are focusing on new techniques that allow the compact integration of dual-band printed antennas into handsets with an increase in their inherent narrow bandwidth. In this letter, novel rectangular, circular, triangular, hexagonal, and bow-tie-shaped spur-line dual-band printed structures have been designed, measured, and compared. Although a second resonant frequency is obtained, it has been clearly made evident that spur-line filter techniques are unable to obtain broad-bandwidth elements, unless they can be combined with other methods.* © 2001 John Wiley & Sons, Inc. Microwave Opt Technol Lett 30: 205−207, 2001.

Key words: *microstrip antennas; spur-line filters*

INTRODUCTION

Mobile telephony represents one of the most rapid market growths in recent years which, in fact, has had a very direct impact on the fast development of different new mobile systems and technologies. Handsets that operate in dual-mode GSM900/DCS1800 are only the previous step toward multi-band−multifunction terminals, which are going to become fashionable in third-generation systems. Convergence between mobile phones and complete Internet services is fast approaching reality.

For this purpose, handsets must adapt to the new services, and thus there will be complex terminals with numerous features such as large and tactile displays, taking on the functions of a keyboard and an improved resolution. As a consequence of this migration, a necessary evolution of the current GSM system ultimately reduces to a single multi-band−multifunction handset allowing users to switch freely between all existing cellular networks. To attain the desired interoperativity, researchers and operators find the monopole alternative of multiband printed antennas as the best option. In this letter, several dual-band printed antennas with different shapes are presented, and since only rectangular-like spur-line dual-band antennas have been previously published in the literature, either with coaxial or aperture-coupled feeds [1−2], important bandwidth-related conclusions have been obtained. The antennas presented here have been designed and analyzed through EM simulation, and constructed and measured in order to determine and compare their behavior at two different frequency bands, centered at 900 MHz and 1.8 GHz.

DESIGN METHODOLOGY

Dual-band printed antennas for GSM/DCS1800 systems must operate at two different frequencies, 900 MHz and 1.8 GHz. It is known that the conventional printed-antenna resonance frequency strongly depends upon its physical size. Therefore, in order to satisfy the requirement of small size, patches have been designed at a higher operation frequency, i.e., 1.8 GHz.