PAPER

Analysis of Optical PPM/CDMA System with M-Ary Convolutional Coding*

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SUMMARY Optical Code Division Multiple Access (OCDMA) has been emerging as an attractive scheme in fiber optic communication systems as well as in space communication systems in past few years [1]–[6]. In OCDMA systems, M-ary Pulse Position Modulation (PPM), has been regarded as an efficient signalling format which has the capability to reduce the channel interference caused by the other users and also to increase the number of simultaneous users [3]–[5]. We apply error control coding to improve the system performance of pulse position modulated OCDMA (PPM/OCDMA) systems and this paper investigates the performance of M-ary PPM/OCDMA systems with M-ary convolutional coding. Dual-k code [7] is used as the M-ary convolutional code and Optical Orthogonal Codes with the maximum cross correlation value of 1 and 2 are employed as the signature sequences. We derive an expression for the bit error probability of the new system and show that combining M-ary convolutional coding and M-ary PPM results in an improved error performance. Also it is shown that the number of simultaneous users can be significantly increased with the proposed system compared to the uncoded PPM/OCDMA system with the same bit error probability and with the same information bit rate. We also analyze the system with binary convolutional coding and a comparison with the proposed system is given.

key words: *optical CDMA, pulse-position modulation, M-ary, convolutional coding, dual-k code*

1. Introduction

In recent research, there is a significant interest in Optical Code Division Multiple Access (OCDMA) systems due to its many attractive features, such as, vast bandwidth offered by the optical links, extra-high optical signal processing offered by the optical components, possibility of accommodating large number of simultaneous users [1], etc.

Figure 1 shows the general block diagram of an OCDMA system. The system is composed of N number of simultaneous users and each user is assigned a unique signature sequence. Data of each user modulates a laser source by On-Off Keying (OOK) or Pulse Position Modulation (PPM) schemes. This modulated signal is then multiplied by a high rate signature sequence at the OCDMA encoder and it is then transmitted over an optical channel through a star coupler. At the receiving end the signal is composed of the data of all N users. The data of a desired user is recovered by comparing it with a stored replica of that user's signature sequence. The interference caused by the other users becomes high with the increase in the number of simultaneous users. Various solutions have been proposed in recent research to overcome this problem [2]. OCDMA systems with M-ary pulse position modulation signalling (PPM/OCDMA) has been studied as an emerging scheme for reducing the channel interference caused by the other users [3]. Its simple implementation and efficient use of the available source energy has made this scheme an attractive option in optical communications. Furthermore, it has the capability of accommodating more simultaneous users than direct detection OCDMA systems with OOK signalling (OOK/OCDMA) [4], [5].

Bit error probability is a key parameter in almost all types of digital communication systems and the primary objective of many research work is to reduce the bit error probability of the system under consideration. In [6], external channel coding has been shown to be more effective in improving the probability of error performance of the OCDMA network. In order to reduce the channel interference further in OCDMA systems, we apply channel coding for PPM/OCDMA systems.

In this paper we analyze M-ary PPM/OCDMA system with M-ary convolutional coding as the channel coding method and show that significant improvement in probability of error performance is possible along with an increase in number of simultaneous users. Performance characteristics under variety of system parameters are shown to validate the arguments. Here we use M-ary convolutional coding as it is suitable for

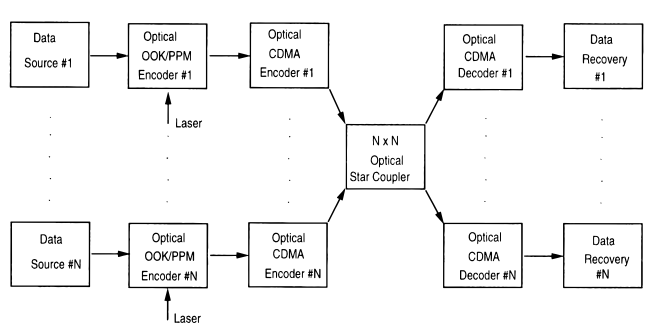

Fig. 1 Block diagram of a general optical CDMA system.

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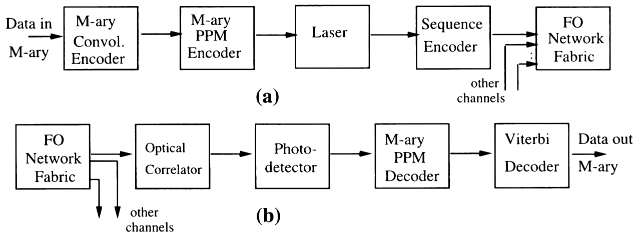

Fig. 2 Optical PPM/CDMA system with M-ary convolutional coding: (a)transmitter (b)receiver.

M-ary PPM signalling. In case of binary convolutional coding with M-ary PPM signalling, when a symbol error occurs it directly affects multiple bits of the decoded information whereas in M-ary convolutional coding, a symbol error has a reduced effect on the decoded sequence if other corresponding symbols are correct.

In this work we assume that the performance degradation is only due to the effects of the interference from the other users. Furthermore, it is assumed that all users have the same optical power at the receiver and all the derivations are done for the chip synchronous case. We use (L, w, λ) Optical Orthogonal Codes (OOC's) as the signature sequences, where L is the code length, w is the code weight and λ is the maximum cross correlation value.

The rest of the paper is organized as follows. In Sect. 2 our proposed method is described in detail. The derivation of bit error probability of the new system is shown in Sect. 2.1. For the purpose of comparison, Sect. 3 gives an analysis of the system with binary convolutional coding. Section 4 gives the numerical results of the analysis of the system for OOC's with $\lambda = 1$ and $\lambda = 2$. Finally we give our conclusions.

2. Proposed System

Figures 2(a) and 2(b) show the transmitter and receiver block diagrams of the proposed system respectively. The system is composed of N simultaneous users and each user transmits M-ary data symbols. Each M-ary data symbol is encoded into n M-ary symbols by $1/n$ non-binary convolutional encoder. Here we use dual-k ($M = 2^k$) code [7] as the non-binary convolutional code. Figure 3 shows the rate 1/2 dual-3 convolutional encoder. Dual-k convolutional encoder consists of two k-bit shift registers and for each k-bit symbol shifted in, n encoded symbols are available at the output. Each of these is transmitted as an optical pulse in one of M available slots in the PPM frame at the PPM encoder and it is then multiplied by the signature sequence at the optical sequence encoder.

In M-ary PPM signalling, the information bits are grouped into k-bit words and the optical pulse sequence is transmitted in one of the $M (M = 2^k)$ time slots of PPM frame which represents the k-bit word. When the slot duration is T_s s, the symbol is extended over a time

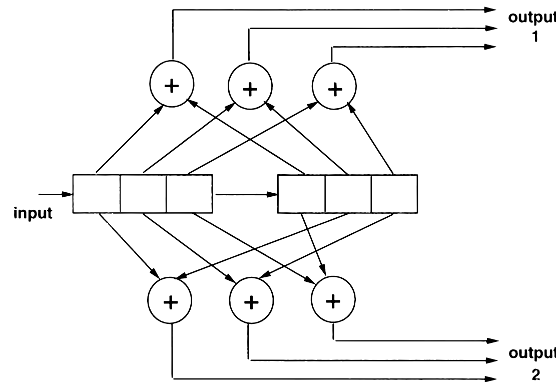

Fig. 3 Rate 1/2 dual-3 convolutional encoder.

frame of MT_s s. As PPM encoding distributes the pulse locations of all N transmitters over the PPM frame, the effect of interference to any one slot is reduced. When length and number of pulses in a sequence of the signature sequence are L and w respectively, the chip length T_c is equal to T_s/L. Then, the information bit rate R_b of the system can be expressed as,

$$R_b = \frac{\log_2 M}{MLT_c} \tag{1}$$

When channel coding is applied with code rate $1/n$ to the M-ary PPM/OCDMA system, the information bit rate is given by,

$$R_b = \frac{\log_2 M}{MLT_c}\frac{1}{n} \tag{2}$$

This means that with channel coding, the information bit rate is reduced by n times than that of the uncoded system when the code rate is $1/n$.

In order to reduce the interference caused by other users, the signature sequence should be designed with minimum off-peak auto correlation and cross correlation values. OOC's with maximum cross correlation value $\lambda = 1$, is a code which satisfies the above condition and can thus be considered as an optimum code [1].

At the receiver the signal is passed through the optical correlator followed by the photo-detector and then PPM position is located by taking the slot which has the maximum detector output. The PPM decoder output which consists of M-ary data symbols is sent to the Viterbi decoder, from which the corresponding data sequence can be decoded. In Viterbi decoding, the decoding complexity is measured by the number of states of the code trellis. When the number of input bits at a time is b and the constraint length of the convolutional coder is K, then there are $2^{b(K-1)}$ number of states in the trellis. In dual-k convolutional coding, the number of shift register levels, i.e. the constraint length, $K = 2$ and $b = k$. Therefore the decoding complexity becomes 2^k. This means that when dual-k convolutional coding is used, the decoding complexity of the Viterbi decoder depends only on the value of k.

2.1 Derivation of Bit Error Probability (P_b)

In this section we derive the bit error probability of PPM/OCDMA system with M-ary convolutional coding (M-ary CC/PPM-OCDMA).

In non-binary convolutional encoding, the input consists of blocks of k bits which in turn form k-bit (M-ary) symbols that can be represented by the integers 0,1,. . .,M-1. The output sequence of the non-binary encoder also consists of k-bit (M-ary) symbols. In our proposed system, the received sequence to the Viterbi decoder is the PPM decoder output, which consists of M-ary symbols. In hard decision Viterbi decoding, this received sequence is decoded by comparing the M-ary symbols of the received sequence with the M-ary symbols associated with each path in the trellis. The path which has the minimum distance is selected as the correct path. The symbol error probability, PWE, is upper bounded by [8],

$$PWE \leq \sum_{d=d_f}^{\infty} \beta_d P_d \tag{3}$$

where, P_d is the pairwise probability between the correct path and an incorrect path that has a distance d symbols from the correct path. β_d is the total number of information symbol errors produced by the incorrect paths of distance d symbols from the correct path and d_f is the minimum free distance. Then the bit error probability is upper bounded as [8],

$$P_b \leq \frac{2^{k-1}}{2^k - 1} PWE \tag{4}$$

In order to determine P_d in Eq.(3), we calculate the pairwise error probability between the all zero path and a path in distance d symbols from the all zero path, assuming that all zero sequence has been transmitted.

The correct path is selected when the number of zeros (i.e. symbols which are equal to the correct path) in the d symbols of the received sequence, is greater than or equal to the number of equal symbols, between the incorrect and the received sequence, within those d symbols.

Let, n_1 = the number of zero symbols (i.e. symbols which are equal to the correct path) within the d symbols of the received sequence.
n_2 = the number of equal symbols, between the incorrect and the received sequence, within those d symbols.

The correct path is selected, when $n_1 \geq n_2$.
The incorrect path is selected, when $n_1 \leq n_2$.

The probability of symbol error can now be written as,

$$P_d = P\{n_1 < n_2\} + \frac{1}{2} P\{n_1 = n_2\} \tag{5}$$

Here we assume the PPM/OCDMA channel as an M-ary Uniform Discrete Memoryless Channel.

$P(n_1)$ is the probability of n_1 number of correct symbols being in the received sequence within those d symbols and $P(n_2)$ is the probability of n_2 number of symbols being in the received sequence which are equal to the corresponding symbols in the incorrect sequence, within those d symbols.

$$P(n_1) = \binom{d}{n_1} (P_c)^{n_1} (1 - P_c)^{d-n_1} \tag{6}$$

$$P(n_2) = \binom{d}{n_2} (p)^{n_2} (1 - p)^{d-n_2} \tag{7}$$

where, $P_c = 1 - (M-1)p$ and p is the transition probability of a PPM/OCDMA channel. Derivation of p for the cases, OOC's with $\lambda = 1$ and $\lambda = 2$ are given in Sect. 2.2 and in Sect. 2.3 respectively.

$$\begin{aligned} P\{n_1 < n_2\} &= \sum_{n_2=0}^{d} \sum_{n_1=0}^{n_2-1} P(n_1).P(n_2) \\ &= \sum_{n_2=0}^{d} \sum_{n_1=0}^{n_2-1} \binom{d}{n_1} (P_c)^{n_1} (1 - P_c)^{d-n_1} \\ &\quad \cdot \binom{d}{n_2} (p)^{n_2} (1-p)^{d-n_2} \end{aligned} \tag{8}$$

$$\begin{aligned} P\{n_1 = n_2\} &= \sum_{n_1=0}^{d} \binom{d}{n_1} (P_c)^{n_1} (1 - P_c)^{d-n_1} \\ &\quad \cdot \binom{d}{n_1} (p)^{n_1} (1-p)^{d-n_1} \end{aligned} \tag{9}$$

By substituting Eqs. (8) and (9) in Eq. (5), P_d can be calculated. From Eqs. (3) and (4), P_b of the system can be determined.

2.2 OOC's with $\lambda = 1$

In OOC's with $\lambda = 1$, the maximum number of simultaneous users N_{max} is upper bounded by $\frac{(L-1)}{w(w-1)}$ [9].

Assuming equally likely data symbols, the transition probability of M-ary PPM/OCDMA channel with $\lambda = 1$ OOC's can be expressed as,

$$\begin{aligned} p \leq &\sum_{i=w+1}^{N-1} \binom{N-1}{i} (p')^i (1-p')^{N-1-i} \\ &+ \frac{1}{2} \binom{N-1}{w} (p')^w (1-p')^{N-1-w} \end{aligned} \tag{10}$$

where p' is the probability that any one interfering transmitter produces a pulse overlap in any one of the M slots in PPM frame i.e. $p' = w^2/ML$.

2.3 OOC's with $\lambda = 2$

In OOC's with $\lambda = 2$, the maximum number of simultaneous users, N_{max} is upper bounded by $\frac{(L-1)(L-2)}{w(w-1)(w-2)}$ which is much higher than N_{max} for $\lambda = 1$ [9]. For example when $L = 100$ and $w = 4$, OOC's with $\lambda = 2$ gives N_{max} of 161 whereas OOC's with $\lambda = 1$ gives only 4. However, in OOC's with $\lambda = 2$, the interference caused by other users is higher than that with $\lambda = 1$ OOC's since it has a high correlation. This in turn places limits on the possibility of increasing the number of simultaneous users. If we could reduce this interference, that would be more advantageous than using OOC's with $\lambda = 1$. This is the major reason for the proposed system being analyzed with OOC's with $\lambda = 2$ as the signature sequences.

In case of OOC's with $\lambda = 2$, two codewords overlap at one pulse position as well as at two pulse positions [9]. Therefore the average correlation is a ternary random variable that takes values of 0,1 and 2. Let, l_1 be the number of users interfering at one pulse position, l_2 be the number of users interfering at two pulse positions, q_1 be the probability of having interfering users with one pulse overlap and q_2 be the probability of having interfering users with two pulse overlaps. The relationship between q_1 and q_2 is given by, $q_1 + 2q_2 = \frac{w^2}{ML}$.

An error occurs when the pulse count of an incorrect slot of the PPM frame is greater than the threshold value. When the pulse count of an incorrect slot is equal to the threshold it is randomly decided to be correct or incorrect. If the threshold is set to w, the transition probability of M-ary PPM/OCDMA channel with $\lambda = 2$ OOC's can be expressed as,

$$p = 1 - \sum_{\substack{l_1+2l_2<w \\ l_1+l_2<N}} Pr(l_1, l_2) \tag{11}$$

where,

$$Pr(l_1, l_2) = \frac{(N-1)!}{l_1! l_2! (N-1-l_1-l_2)!} . q_1^{l_1} . q_2^{l_2} \cdot (1-q_1-q_2)^{N-1-l_1-l_2}$$

As given in [9], a parameter c is defined as $c = \frac{q_1}{w^2/ML}$ $(0 \leq c \leq 1)$, which measures the extent to which $\lambda = 2$ code deviates from $\lambda = 1$ code in interference statistics. When $c = 1$, the code becomes an OOC with $\lambda = 1$ and when $c = 0$, two codewords always overlap at 2 pulse positions causing maximum interference (worst case) in the system. Obtaining the largest possible value for c for a desired number of distinct code words must be the goal of the code design.

3. Analysis with Binary Convolutional Coding

In this section, we analyze the performance of the M-ary PPM/OCDMA system with binary convolutional coding (binary CC/PPM-OCDMA) for the purpose of comparison. One may suggest that our proposed system can be generalized into the binary case by setting $M = 2$. However, this is not the case. If the value of M is set to 2, then the system becomes binary PPM/OCDMA with dual-1 convolutional coding. That is only a special case of the method that we are going to describe here.

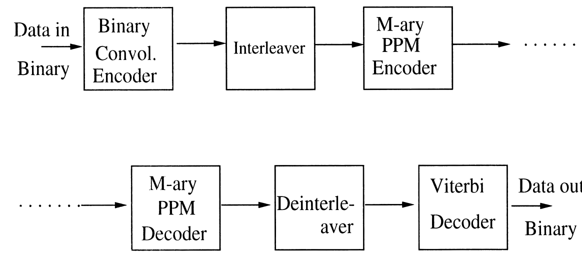

Fig. 4 Insertion of interleaver and deinterleaver necessary for binary CC/PPM-OCDMA system.

In case of binary CC/PPM-OCDMA system an interleaver must be used between the convolutional encoder and the PPM encoder to shield the system from multiple errors, resulted after the conversion of M-ary symbols into binary symbols. Figure 4 shows the insertion of interleaver and deinterleaver for binary convolutional coding. Here, the input and the output of the system are binary and binary Viterbi Decoding is performed at the receiving end, i.e. the comparison is done with bits of the received sequence and bits associated with each path of the trellis. Now, the bit error probability can be expressed as,

$$P_b \leq \sum_{d=d'_f}^{\infty} \beta'_d P'_d \tag{12}$$

where, P'_d is the pairwise error probability between the correct path and an incorrect path that has a distance d bits from the correct path. β'_d is the total number of information bit errors produced by the incorrect paths of Hamming distance d from the correct path and d'_f is the minimum free distance. Now, P'_d can be expressed as [8],

$$P'_d = \begin{cases} \sum_{i=\frac{d+1}{2}}^{d} \binom{d}{i} (p'')^i (1-p'')^{d-i} \\ \quad d-odd \\ \sum_{i=\frac{d}{2}+1}^{d} \binom{d}{i} (p'')^i (1-p'')^{d-i} \\ \quad +\frac{1}{2} \binom{d}{d/2} (p'')^{d/2} (1-p'')^{d-d/2} \\ \quad d-even \end{cases} \tag{13}$$

where, $p'' = (M/2)p$ and here, p is given by Eq. (10) for OOC's with $\lambda = 1$ and by Eq. (11) for OOC's with $\lambda = 2$. The factor $M/2$ comes from the union bound

Table 1 Parameters for some Dual-3 convolutional codes used in this work.

Code rate	d_f	β_{d_f}	β_{d_f+1}	β_{d_f+2}	β_{d_f+3}	β_{d_f+3}	β_{d_f+4}
1/2	4	7	154	644	2765	11144	44436
1/3	6	7	0	42	56	189	504
1/4	7	7	0	0	56	42	0

and the conversion from symbol error to bit error in PPM/OCDMA system [10].

4. Numerical Results and Discussion

The Bit Error Probability P_b is calculated using Eq. (3) and the Table 1 gives d_f and β_d values for some code rates used throughout this work. Even though the range of d in Eq. (3) varies from d_f to infinity, the increase of P_b becomes negligible after about 4 steps. In case of binary convolutional coding we use Eq. (12) and the corresponding d'_f and β'_d values are taken from [11].

4.1 Performance with $\lambda = 1$ OOC's

For the purpose of comparison, the parameters are normalized by keeping the information bit rate and chip duration (T_c) constant for coded and uncoded systems. Let, L_c and w_c be the normalized code length and code weight for the coded system and L_u, w_u be the code length and code weight for the equivalent uncoded system respectively. The information bit rate for the uncoded PPM/OCDMA system is, $\frac{\log_2 M}{M} \cdot \frac{1}{L_u T_c}$. For the coded system the information bit rate is, $\frac{\log_2 M}{M} \cdot \frac{1}{L_c T_c} \cdot r$ where, r is the code rate. By equating the bit rates of coded and uncoded systems with the same T_c,

$$\frac{\log_2 M}{M} \cdot \frac{1}{L_u T_c} = \frac{\log_2 M}{M} \cdot \frac{1}{L_c T_c} \cdot r \tag{14}$$

Then, for N number of simultaneous users, the normalized code length and code weight for coded system can be expressed as follows.

$$L_c = r \cdot L_u$$
$$w_c = \frac{1}{2} + \frac{1}{2}\sqrt{1 + 4(L_c - 1)/N}$$

As an example, consider a system with $L_u = 1000$ and $M = 8$. L_c for each code rate is calculated and corresponding code weight is obtained by considering the system size, N as 40. Figure 5 compares P_b vs. number of users with that of uncoded PPM/OCDMA system. $N = 40$ has been selected so that the comparison can be made for all code rates. However for each code rate, the actual maximum number of users is upper bounded by $\frac{(L-1)}{w(w-1)}$ which results in N_{max} of 41, 55 and 41 for code rates 1/2, 1/3 and 1/4 respectively. Similarly N_{max} is 49 for uncoded system. Figure 5 shows that the P_b decreases with the code rate.

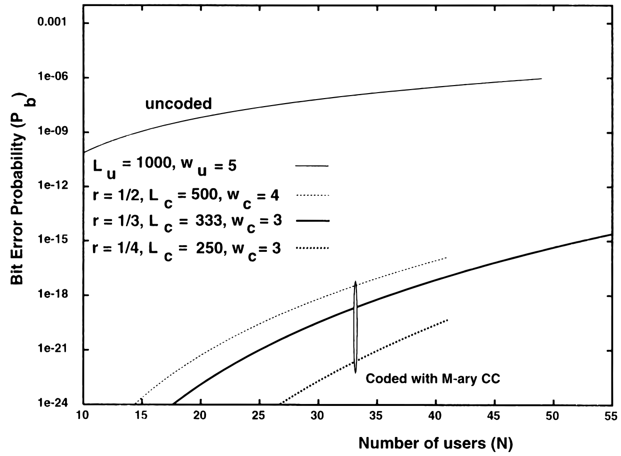

Fig. 5 P_b vs. number of users for different code rates of dual-3 convolutional coder with 8-ary PPM.

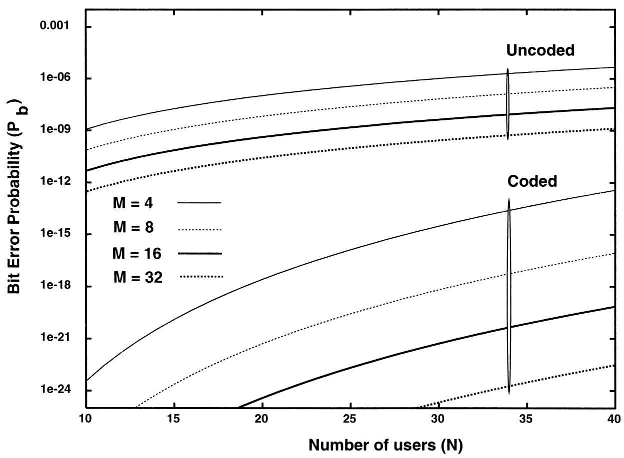

Fig. 6 P_b vs. number of users for different values of M ($L_u = 1000, w_u = 5, L_c = 500, w_c = 4$ and code rate $= 1/2$).

But, in this example, 1/3 is the optimum code rate as it provides the maximum number of users to the system. In convolutional coding minimum free distance d_f increases with decreasing code rates. This results in a significant improvement in the error performance from one code rate to another. However, Figure 5 does not show this clearly due to normalization of parameters. When parameters are normalized under the information bit rate constraint, code length is reduced for lower code rates. When the same number of users are allocated for this reduced code length, the interference increases which results in a reduced difference between the error performance of two consecutive code rates. If the error probability is to be less than 10^{-9}, from Fig. 5, we see that the proposed coded system can accommodate the maximum number of simultaneous users for each code rate whereas the uncoded system can accommodate only 15 users.

Figure 6 shows the variation of P_b with M (i.e. k of dual-k encoder) under the same information bit rate. It

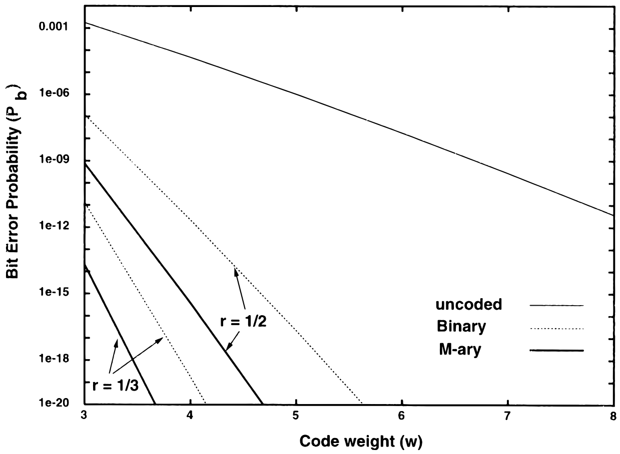

Fig. 7 P_b vs. code weight(w) for the M-ary, binary and uncoded systems when $M = 8$ and $N = 50$.

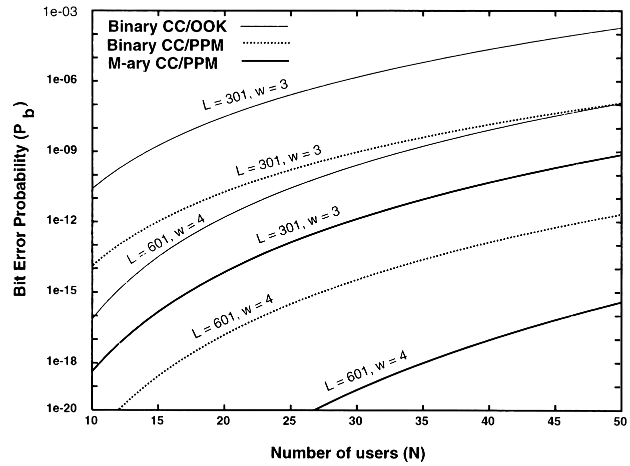

Fig. 8 Comparison of the CC/PPM-OCDMA with CC/OOK-CDMA ($M = 8$ and code rate $= 1/2$).

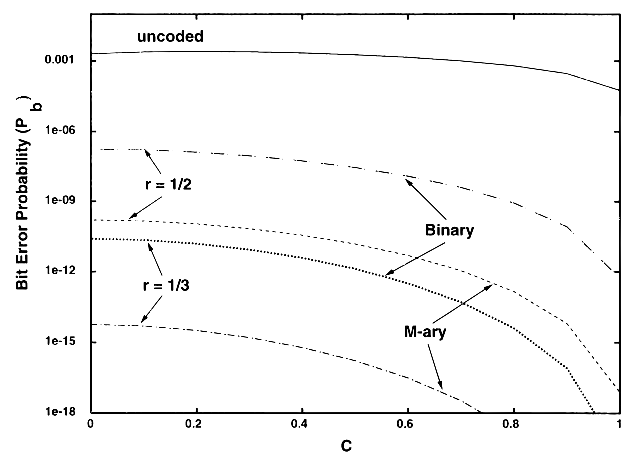

Fig. 9 P_b vs. parameter c, which measures interference statistics($L = 500, w = 5, M = 8$ and $N = 50$).

can be seen that, P_b of the proposed system can also be reduced by increasing M. This is due to the fact that as PPM spreads the pulse locations of the individual users over the PPM frame and consequently, reducing the chance of occurrence of pulse overlaps among users.

The graph of P_b vs. code weight, w for M-ary, binary and uncoded systems when $M = 8$ and $N = 50$, is shown in Fig. 7. Both M-ary and binary systems give a significantly low bit error probability for lower values of w. Low code weights result in short code lengths for a constant N, according to the equation $L \geq Nw(w-1)+1$ (refer Sect. 2.2), which in turn helps to make the optical correlator to be simple. For this comparison the decoding complexities of Viterbi decoder of M-ary and binary decoders are kept constant. (In this example, we use the binary convolutional coder with constraint length, $K = 4$ and the value of M is taken as 8. Then the number of states in the decoding trellis, which indicates the decoding complexity, for binary convolutional decoder is $2^{4-1} = 8$ and that for Dual-k convolutional decoder is $2^3 = 8$.) Although both systems have same decoding complexities as described above, in case of binary convolutional codes with M-ary PPM, the insertion of interleaver and deinterleaver results in an additional hardware to the system.

Figure 8 shows a comparison of P_b vs. number of users in the PPM/OCDMA system with convolutional coding (CC/PPM-OCDMA) and in OOK/OCDMA system with convolutional coding (CC/OOK-OCDMA). This comparison is made by keeping the sequence code length constant. If the bit error probability is to be less than 10^{-9}, from Fig. 8 it is seen that the CC/OOK-OCDMA system accommodates 13 users, binary CC/PPM-OCDMA system accommodates 30 users and M-ary CC/PPM-OCDMA system accommodates 50 users (i.e. the maximum number of users at $L = 301, w = 3$). However, the information bit rate of the PPM/OCDMA system with convolutional coding is $(\log_2 M)/M$ times lower than the CC/OOK-OCDMA. (Binary CC/OOK-OCDMA system has been analyzed in detail in [6].) Hence, if we compare the proposed system with CC/OOK-OCDMA system at the same information bit rate, the normalized code length for CC/PPM-OCDMA becomes very low. This makes CC/OOK-OCDMA system performance to be better under the information bit rate constraint.

4.2 Performance with $\lambda = 2$ OOC's

To increase the maximum number of users, we use OOC's with $\lambda = 2$ as signature sequences. In this case, we need to emphasize that the comparison of the numerical results is done without normalizing the parameters. This means the information bit rate for the coded system is reduced with the code rate. Here, the M-ary and the binary convolutional codes used, have same decoding complexities of Viterbi decoding as in

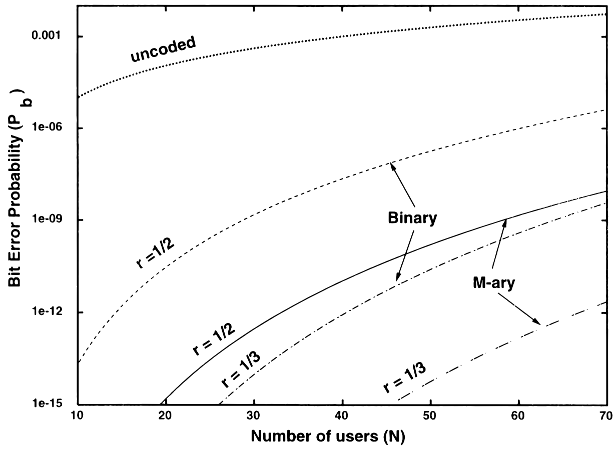

Fig. 10 Comparison of Bit error probabilities for M-ary, binary and uncoded systems ($L = 500, w = 5$, $M = 8$ and $c = 0$).

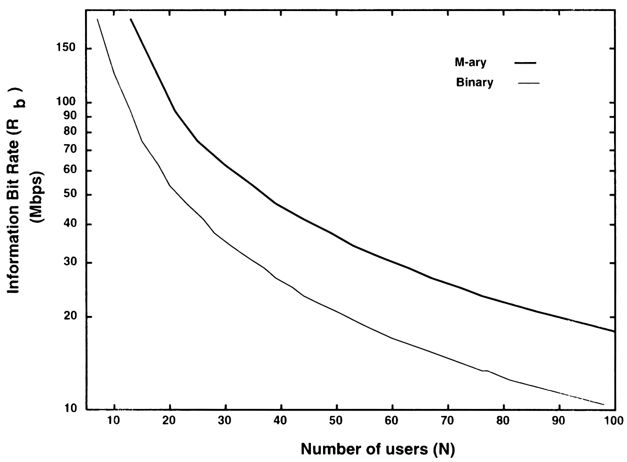

Fig. 11 Comparison of information bit rates for the proposed system with the binary system at $P_b = 10^{-9}$($w = 5$, $M = 8$, $c = 0$, code rate $= 1/2$ and $T_c = 10$ ps).

Fig. 7.

P_b for different c values (from $c = 0 \rightarrow 1$) are shown in Fig. 9. When $c = 0$, the system gives the worst case results i.e. when all codewords overlap at 2 pulse positions.

Figure 10 compares the bit error probabilities between the proposed system with the uncoded PPM/OCDMA system and the system with binary convolutional coding for the worst case i.e. c=0, when $L =$ 500 and $w = 5$. It is clearly seen that applying convolutional coding to the PPM/OCDMA system results in a marked improvement of the system performance even with the worst case interference. Also we can see that our proposed system offers the better results compared to the system with binary convolutional coding under the same decoding complexity.

Figure 11 shows how information bit rate varies with the number of users at the bit error probability of 10^{-9} and the chip duration of 10 ps for M-ary and binary systems. Chip duration (T_c) of 10 ps has recently been recognized as a practically viable value that could be used in actual systems. We can see that both systems perform within the practical range (i.e. tens and hundreds of Mbps). According to the graph in Fig. 11 binary system can accommodate 52 users while M-ary system can accommodate 90 users at a data rate of 20 Mbps. This means that it is possible to accommodate more users with the M-ary system than with the binary system under the same bit error probability and at the same information bit rate.

5. Conclusion

In this paper, we have analyzed M-ary PPM/OCDMA system with M-ary convolutional coding. OOC's with $\lambda = 1$ and $\lambda = 2$ are used as the signature sequences. Performance characteristics of the proposed system is given for different parameters. Furthermore, we analyzed the performance of the M-ary PPM/OCDMA system with binary convolutional coding and compared it with our proposed system.

Performance analysis shows that the proposed system offers significant gains in error performance as well as in the number of simultaneous users. It is also shown that the system performance is further increased as the value of M is increased. OOC's with $\lambda = 2$ are used to increase the maximum number of simultaneous users of the system and we found that the proposed system offers improved bit error performance even with the worst case interference.

Combining convolutional coding and M-ary PPM improves the error performance of the optical CDMA system with moderate information data rates. We show that M-ary CC/PPM-OCDMA system can accommodate more number of users than that of binary CC/PPM-OCDMA system at the same information bit rate and at the same bit error probability under the same decoding complexity of the Viterbi decoder. The reason for this improved performance is that in binary convolutional coding a symbol error causes multiple bit errors in the decoded information sequence whereas in M-ary convolutional coding a symbol error has a reduced effect on the decoded information sequence.

Hardware used for channel coding has been in use for a long time and also it is carried out completely external to the optical system. Thus its use in an optical CDMA network would not result in an undue increase of system complexity. Although most of the convolutional codes currently used in practical systems are binary, M-ary convolutional codes by way of dual-k convolutional codes have been shown to be simple enough for practical implementation [7]. In case of binary CC/PPM-OCDMA system, the insertion of interleaver causes an additional hardware to the system as well as an increase in the decoding delay.

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