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PERFORMANCE EVALUATION OF FAMILY OF PRIME SEQUENCE CODES IN AN OCDMA SYSTEM

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ABSTRACT

In a CDMA system, spreading code play an important role in the system performance. Optical CDMA (OCDMA) takes the advantage of both spread spectrum as well as high bandwidth optical fiber. In an optical communication system, the code length and code weight are one of the factor that determine the number of users the system can accommodate. Also code length have significant role in raising the system performance. Hence longer codes are more beneficial. Among the commonly used optical address codes, prime codes are easy to generate. But the correlation properties of optical orthogonal codes (OOC) are superior to that of prime codes. However, complex algorithms are required for the generation and correlation of OOC. In this paper, the performance of family of prime sequence codes are evaluated by taking code length and code weight as a parameter.

Keywords: Double Padded MPC, Modified PC, New MPC, OCDMA, Prime Code PC.

1. INTRODUCTION

The introduction of fiber optic communication have introduced a dramatic change in the telecommunication industry. Optic fibers are mainly recommended for the systems requiring higher bandwidth. The main advantage of fiber are its higher bandwidth, low loss, less susceptible to electromagnetic interference etc. To efficiently utilize this huge bandwidth and low propagation loss offered by optical fiber, there should be a proper multiple access technique. At present there are three multiple access techniques such as Time division multiple access (TDMA), Wavelength division multiple access (WDMA) and Code division multiple access (CDMA). Among this, both TDMA and WDMA are restricted in either time or wavelength. CDMA is a spread spectrum multiple access technique [1]. In this technique, the entire bandwidth is shared among the users which are assigned a code instead of time slot in TDMA and wavelength in WDMA. Hence the performance of the system mainly depend on the codes assigned. To avoid the interactions among the users, the codes are designed to be orthogonal to each other with maximum autocorrelation and minimum cross correlation.

A fiber optic code division multiple access (FO-CDMA) or simply optical code division multiple access (OCDMA) system allows multiple users to transmit data simultaneously over the high bandwidth offered by the fiber. A typical FO-CDMA system is represented in figure 1 [2], which includes a data source and an optical encoder, used to map each bit of information into high rate optical sequence. This optical pulses are then coupled into the fiber channel. At the receiver, the information is retrieved using correlation process.

The remainder of this paper is organized as: Section II describes the optical code division multiple access and section III-VI describes the codes in the prime code family. Section VII concludes the paper.

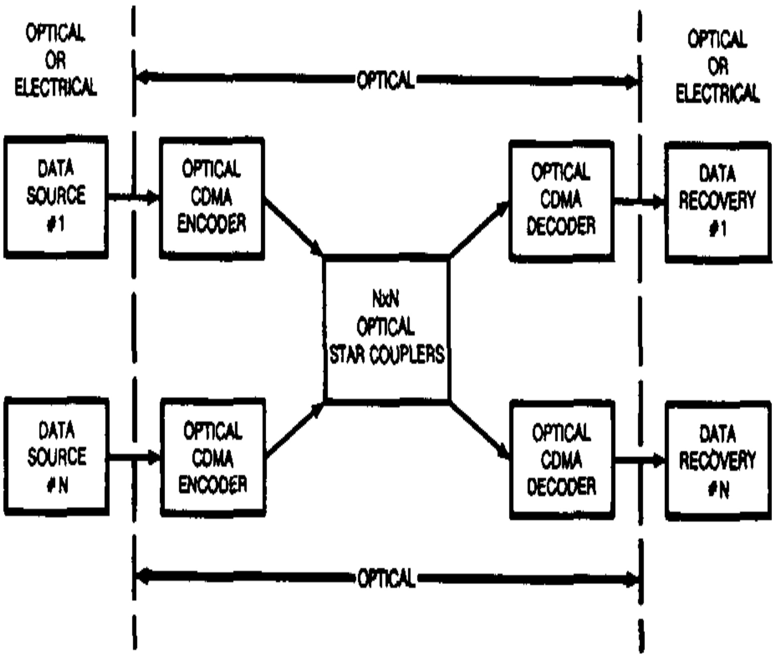

Fig: 1: OCDMA System

2. OCDMA

Optical CDMA is a technique in which, the huge bandwidth offered by the optic fiber is shared among number of active users in a broadcast local area network. OCDMA offers the capability to support large number of users than TDMA or WDMA, especially 2D-CDMA system where the codes are spread in both time and wavelength simultaneously. Normally, there are two types of optical CDMA system: incoherent and coherent OCDMA system. Incoherent OCDMA has less complexity. Coherent OCDMA requires complex receiving schemes for dispreading at the receiver. This makes manufacture of optical system more difficult and expensive. In this paper incoherent OCDMA is considered.

In CDMA system, each user have a unique code. Only the receiver who knows the same code can retrieve the information. To recognize the intended user's signal in presence of other user's signal, the codes used should have good correlation properties i.e., the spreading codes with maximum autocorrelation and minimum cross correlation should be selected. Hence spreading code plays an important role in system performance. The notable difference between OCDMA system and wireless CDMA is the code structure. Since the optical systems are intensity modulated, the chips in OCDMA systems are alternating '1's and '0's. The two main optical spreading codes are prime codes [3] and optical orthogonal codes (OOC) [4]. The OOC have better autocorrelation and cross correlation properties than prime codes. However, to generate and correlate OOC, complex algorithms are needed [4]. Prime codes are easy to generate. In this paper the study of various prime sequence codes are done by considering code length and code weight as a parameter.

3. PRIME CODES (PC)

The generation of prime codes is relatively simple. The construction of prime codes is divided into two steps[5]

1) From the Galois field, GF(P)=(0, 1,…,k,….P-1), where P denotes prime number, a prime sequence $S_X=(S_{X0},S_{X1}\ldots.S_{X(P-1)})$ is generated. The prime sequence is generated as : $S_{Xj}=x.j.(\text{mod } P)$, where x, j € {0,1,..,P-1}.

2) Each prime sequence is then mapped into a binary code sequence $C_X=(C_{X0},C_{X1}\ldots.C_{Xj}\ldots.C_{X(P2-1)})$ according to the rule:

$$C_X = \begin{cases} 1, \text{for i} = Sxj + jP, j = 0,1, \ldots. P-1 \\ 0, \; Otherwise \end{cases}$$

Here prime code sequence set with a code length of P^2 and code weight of P have only P distinct sequences. Example of prime code sequence set with P=5 is shown in Table 1 [6].

Table 1: Prime Code Sequence for P=5

Groups x	i 0 1 2 3 4	Sequence	PC Sequences
0	0 0 0 0 0	S_0	C_0 = 10000 10000 10000 10000 10000
1	0 1 2 3 4	S_1	C_1 = 10000 01000 00100 00010 00001
2	0 2 4 1 3	S_2	C_2 = 10000 00100 00001 01000 00010
3	0 3 1 4 2	S_3	C_3 = 10000 00010 01000 00001 00100
4	0 4 3 2 1	S_4	C_4 = 10000 00001 00010 00100 01000

The main limitation associated with prime code is the limited number of available sequences. Therefore, the number of possible subscribers that the system can include is also limited. Also, the code length of prime code is only P^2, which may affect the system performance in terms of BER, MAI etc. Therefore longer codes that maintain desired properties are beneficial.

4. MODIFIED PRIME CODES (MPC)

Modified prime codes was actually proposed to overcome the drawbacks of prime codes. Modified prime code could be generated by P-1 times shifting of the previous PC sequences. The code is capable to support P^2 number of subscribers with P groups containing P sequences and the length of the code sequence equal to P^2, where P is a prime number. The MPC could be generated as, at first the original PC sequence is rotated left (or right). Then new time shifted sequences $S_{X,t=(}S_{Xt0},S_{Xt1},\ldots\ldots S_{Xt(P-1))}$are obtained, where t represents the number of times S_X has been left (or right) rotated. Then the binary code sequence is generated according to the rule:

$$C_X = \begin{cases} 1, \text{for i} = Sxtj + jP, j = 0,1,\ldots.P-1 \\ 0, \ \ Otherwise \end{cases}$$

Example of MPC with P=5 is shown in Table 2 [7]. Here MPC sequences with P^2 and code weight P, generates P^2 distinct code sequences. Therefore, in a CDMA system using MPC, the number of possible subscribers extended up to P^2, which is larger than PC. However, the code length of MPC is same as that of the PC.

Table 2: Modified Prime Code Sequence for P=5

Group	Code Sequences
0	$C_{0,0}$= 10000 10000 10000 10000 10000
	$C_{0,1}$= 00001 00001 00001 00001 00001
	$C_{0,2}$= 00010 00010 00010 00010 00010
	$C_{0,3}$= 00100 00100 00100 00100 00100
	$C_{0,4}$= 01000 01000 01000 01000 01000
1	$C_{1,0}$= 10000 01000 00100 00010 00001
	$C_{1,1}$= 01000 00100 00010 00001 10000
	$C_{1,2}$= 00100 00010 00001 10000 01000
	$C_{1,3}$= 00010 00001 10000 01000 00100
	$C_{1,4}$= 00001 10000 01000 00100 00010
2	$C_{2,0}$= 10000 00100 00001 01000 00010
	$C_{2,1}$= 00100 00001 01000 00010 10000
	$C_{2,2}$= 00001 01000 00010 10000 00100
	$C_{2,3}$= 01000 00010 10000 00100 00001
	$C_{2,4}$= 00010 10000 00100 00001 01000
3	$C_{3,0}$= 10000 00010 01000 00001 00100
	$C_{3,1}$= 00010 01000 00001 00100 10000
	$C_{3,2}$= 01000 00001 00100 10000 00010
	$C_{3,3}$= 00001 00100 10000 00010 01000
	$C_{3,4}$= 00100 10000 00010 01000 00001
4	$C_{4,0}$= 10000 00001 00010 00100 01000
	$C_{4,1}$= 00001 00010 00100 01000 10000
	$C_{4,2}$= 00010 00100 01000 10000 00001
	$C_{4,3}$= 00100 01000 10000 00001 00010
	$C_{4,4}$= 01000 10000 00001 00010 00100

So to have better correlation and to reduce error rate, longer sequences with desired properties are essential.

5. NEW MODIFIED PRIME CODES

The New Modified Prime (n-MPC) code [6] is generated through repeating the last sequence of the previous modified prime code sequence and rotating in the same group. The code has P groups where each group contain P code sequence. Hence a system using new modified prime code can accommodate P^2 number of subscribers, which is similar to that of modified prime code. Here each number of available sequence has a code length of P^2+P and code weight of P+1.

The increased code length and code weight of new modified prime code enhances the correlation properties of n-MPC than MPC and PC. However the increase in the weight in the code further increases the transmitting power. Example of n-MPC with P=5 is shown in Table 3[6]. It consists of two parts: Modified prime code sequences and padded sequence.

Table 3: New Modified Prime Code Sequence for P=5

Group *x*	*i* 0 1 2 3 4	Sequence	MPC Sequences	Padded Sequence
	0 0 0 0 0	$S_{0,0}$	$C_{0,0}$ = 10000 10000 10000 10000 *<u>10000</u>*	***01000***
	4 4 4 4 4	$S_{0,1}$	$C_{0,1}$ = 00001 00001 00001 00001 00001	*<u>10000</u>*
0	3 3 3 3 3	$S_{0,2}$	$C_{0,2}$ = 00010 00010 00010 00010 00010	00001
	2 2 2 2 2	$S_{0,3}$	$C_{0,3}$ = 00100 00100 00100 00100 00100	00010
	1 1 1 1 1	$S_{0,4}$	$C_{0,4}$ = 01000 01000 01000 01000 ***01000***	00100
	0 1 2 3 4	$S_{1,0}$	$C_{1,0}$ = 10000 01000 00100 00010 00001	00010
	1 2 3 4 0	$S_{1,1}$	$C_{1,1}$ = 01000 00100 00010 00001 10000	00001
1	2 3 4 0 1	$S_{1,2}$	$C_{1,2}$ = 00100 00010 00001 10000 01000	10000
	3 4 0 1 2	$S_{1,3}$	$C_{1,3}$ = 00010 00001 10000 01000 00100	01000
	4 0 1 2 3	$S_{1,4}$	$C_{1,4}$ = 00001 10000 01000 00100 00010	00100
	0 2 4 1 3	$S_{2,0}$	$C_{2,0}$ = 10000 00100 00001 01000 00010	01000
	2 4 1 3 0	$S_{2,1}$	$C_{2,1}$ = 00100 00001 01000 00010 10000	00010
2	4 1 3 0 2	$S_{2,2}$	$C_{2,2}$ = 00001 01000 00010 10000 00100	10000
	1 3 0 2 4	$S_{2,3}$	$C_{2,3}$ = 01000 00010 10000 00100 00001	00100
	3 0 2 4 1	$S_{2,4}$	$C_{2,4}$ = 00010 10000 00100 00001 01000	00001
	0 3 1 4 2	$S_{3,0}$	$C_{3,0}$ = 10000 00010 01000 00001 00100	00001
	3 1 4 2 0	$S_{3,1}$	$C_{3,1}$ = 00010 01000 00001 00100 10000	00100
3	1 4 2 0 3	$S_{3,2}$	$C_{3,2}$ = 01000 00001 00100 10000 00010	10000
	4 2 0 3 1	$S_{3,3}$	$C_{3,3}$ = 00001 00100 10000 00010 01000	00010
	2 0 3 1 4	$S_{3,4}$	$C_{3,4}$ = 00100 10000 00010 01000 00001	01000
	0 4 3 2 1	$S_{4,0}$	$C_{4,0}$ = 10000 00001 00010 00100 01000	00100
	4 3 2 1 0	$S_{4,1}$	$C_{4,1}$ = 00001 00010 00100 01000 10000	01000
4	3 2 1 0 4	$S_{4,2}$	$C_{4,2}$ = 00010 00100 01000 10000 00001	10000
	2 1 0 4 3	$S_{4,3}$	$C_{4,3}$ = 00100 01000 10000 00001 00010	00001
	1 0 4 3 2	$S_{4,4}$	$C_{4,4}$ = 01000 10000 00001 00010 00100	00010

6. DOUBLE PADDED MODIFIED PRIME CODE

For the code to be more secure and to operate at higher bit rate, the code should have increased chip rate (processing factor in spreading). The double padded modified prime code (DPMPC) id generated through padding (firstly) the final sequence stream of the MPC sequence and (secondly) the final stream sequence of the previous modified prime sequence (rotating) in the same group [8]. The padded sequence cannot only be the final sequence of MPC, but any sequence stream of the MPC sequence. The cross-correlation value changes into undesirable values (increases), if the padding order changes during code generation. Therefore padding has to be followed for the whole code sequences. Through this double padding, the code enlarges by 2P as compared with MPC and by P as compared with n-MPC. This makes an increase in the chip rate. The difference between autocorrelation and cross-correlation is also enhanced. This feature helps during detection and reduces multiple access interference considerably. However longer codes brings complexity in the system. The DPMPC has P groups, each group have P code sequences. Hence capable to accommodate P^2 subscribers. Compared with other codes in the prime code family, the code length increases to P^2+2P and code weight to P+2. [8]

The code length of double padded modified prime code is higher than the code length of the codes mentioned above. The expansion of code length of DPMPC result in excellent correlation property. Due to the increase in the chip rate, the code becomes more secure and raise the system performance by reducing the multiple access interference (MAI) and also the error rate. Example of a double padded modified prime code with prime sequence number P=5 is shown in Table 4 [6]. In this each code consists of two parts: modified prime code (MPC) and group stream sequence (GSS).

Table 4: Double Padded Modified Prime Code Sequence for P=5

Group x	i 0 1 2 3 4	Sequence	MPC Part	GSS Part
	0 0 0 0 0	$S_{0,0}$	$C_{0,0}$ = 10000 10000 10000 10000 *10000*	*10000* ***01000***
	4 4 4 4 4	$S_{0,1}$	$C_{0,1}$ = 00001 00001 00001 00001 *00001*	*00001* *10000*
0	3 3 3 3 3	$S_{0,2}$	$C_{0,2}$ = 00010 00010 00010 00010 00010	00010 00001
	2 2 2 2 2	$S_{0,3}$	$C_{0,3}$ = 00100 00100 00100 00100 00100	00100 00010
	1 1 1 1 1	$S_{0,4}$	$C_{0,4}$ = 01000 01000 01000 01000 ***01000***	01000 00100
	0 1 2 3 4	$S_{1,0}$	$C_{1,0}$ = 10000 01000 00100 00010 00001	00001 00010
	1 2 3 4 0	$S_{1,1}$	$C_{1,1}$ = 01000 00100 00010 00001 10000	10000 00001
1	2 3 4 0 1	$S_{1,2}$	$C_{1,2}$ = 00100 00010 00001 10000 01000	01000 10000
	3 4 0 1 2	$S_{1,3}$	$C_{1,3}$ = 00010 00001 10000 01000 00100	00100 01000
	4 0 1 2 3	$S_{1,4}$	$C_{1,4}$ = 00001 10000 01000 00100 00010	00010 00100
	0 2 4 1 3	$S_{2,0}$	$C_{2,0}$ = 10000 00100 00001 01000 00010	00010 01000
	2 4 1 3 0	$S_{2,1}$	$C_{2,1}$ = 00100 00001 01000 00010 10000	10000 00010
2	4 1 3 0 2	$S_{2,2}$	$C_{2,2}$ = 00001 01000 00010 10000 00100	00100 10000
	1 3 0 2 4	$S_{2,3}$	$C_{2,3}$ = 01000 00010 10000 00100 00001	00001 00100
	3 0 2 4 1	$S_{2,4}$	$C_{2,4}$ = 00010 10000 00100 00001 01000	01000 00001
	0 3 1 4 2	$S_{3,0}$	$C_{3,0}$ = 10000 00010 01000 00001 00100	00100 00001
	3 1 4 2 0	$S_{3,1}$	$C_{3,1}$ = 00010 01000 00001 00100 10000	10000 00100
3	1 4 2 0 3	$S_{3,2}$	$C_{3,2}$ = 01000 00001 00100 10000 00010	00010 10000
	4 2 0 3 1	$S_{3,3}$	$C_{3,3}$ = 00001 00100 10000 00010 01000	01000 00010
	2 0 3 1 4	$S_{3,4}$	$C_{3,4}$ = 00100 10000 00010 01000 00001	00001 01000
	0 4 3 2 1	$S_{4,0}$	$C_{4,0}$ = 10000 00001 00010 00100 01000	01000 00100
	4 3 2 1 0	$S_{4,1}$	$C_{4,1}$ = 00001 00010 00100 01000 10000	10000 01000
4	3 2 1 0 4	$S_{4,2}$	$C_{4,2}$ = 00010 00100 01000 10000 00001	00001 10000
	2 1 0 4 3	$S_{4,3}$	$C_{4,3}$ = 00100 01000 10000 00001 00010	00010 00001
	1 0 4 3 2	$S_{4,4}$	$C_{4,4}$ = 01000 10000 00001 00010 00100	00100 00010

7. DISCUSSIONS AND CONCLUSION

In this paper the performance analysis of various codes from the prime code family are evaluated on the basis of code length as well as code weight. [9]Suggests that the code length play an important role in raising the system performance in terms of multiple access interference (MAI), BER, and throughput. So, longer codes that maintain the desired properties are essential. In an optical fiber communication system a BER of 10^{-9} is desired. As the number of simultaneous users increases, the bit error rate also increases.[5]Shows that as the prime number P increases, the bit error rate reduces. For higher values of P, there is a less difference in the bit error rate. The BER further decreases with the increase of code weight. Generally, a BER of 10^{-9} is sufficient. Therefore, lower values of P can be used to get the same BER.

The reduction in BER is more for less number of simultaneous users compared to more simultaneous users. To increase the number of subscribers with less bit error rate, the correlation properties, resistance to interference must be improved. Therefore longer sequences with desired properties are essential. By increasing the prime sequence number and weight, more number of simultaneous uses can be accommodated. However the increase of the weight in the code further increases the transmission power. So it is better to increase the prime sequence number P than weight, because for higher values of simultaneous users there is a less difference in the bit error rate by reducing the value of P.

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