Optical Code Division Multiple Access and Prime Codes: An Overview

Indu Bala
School of Electronics & Electrical Engigerring
Lovely Professional University, Phagwara,Punjab, India

Abstract: Optical-CDMA technology has been investigated in the last twenty years. However, there are still some possibilities to implement the such system based on the total number of subscribers and system complexity. The type of codes used influencing the performance of optical code division multiple access (OCDMA) system. Various Prime codes for the optical CDMA system implementation have been reported so far. But, their comparison on a single realizable incoherent system has been done rarely. The Optical Code Division Multiplexing Access (OCDMA) has potential to overcome all the glitches associated with existing communication networks like channel degradation, channel allocation, fixed bit rate, security etc. In this paper, OCDMA system is discussed in detail and the comparison of various prime codes and future scope has also been discussed.

Keywords- Prime Codes, Optical Code division Multiple Access (OCDMA), Code Cardinality, Bit Error Rate (BER).

I. INTRODUCTION

Our world is rapidly changing in term of technologies and their usage. The internet traffic has increased exponentially and thus, today's communication networks information carrying capacity pose some serious concerns. The information capacity of any communication system depends upon the frequency of carrier. Since, optic communication systems use light as a carrier, they are having highest information carrying capacity. This feature makes optical fiber communication more attractive as compare to the other solutions available in a market to implement next generation communication networks [1]. The optical systems have advantages like less interference, low system losses and high bandwidth. Thus, to use the full potential of available bandwidth in optical fiber, it is necessary to multiplex low data rate electrical signal into high data rate optical pulses to increase the overall throughput of system. But, the O/E and E/O conversion on optical fiber based communication networks does not allow users to make full use of available fiber's bandwidth [2-4]. Therefore, next generation optical communication networks needs advanced signal-processing operations in optical domain based on the requirements [5].

Optical Code Division Multiplexing Access (OCDMA) technology exploits full bandwidth of optical fiber by converting electrical signals into optical signals to have an asynchronous decentralized control among subscribers [2]. The basic notion of using this multiplexing access technique has been adapted from wireless CDMA developed for Radio Frequency (RF) communication systems. Prucnal and Salehi, duo were first to apply the concept of CDMA in optical domain in mid 1980s. A typical Optical CDMA communication network consists of "N" transmitters/receivers using star configuration depicted in Fig.1

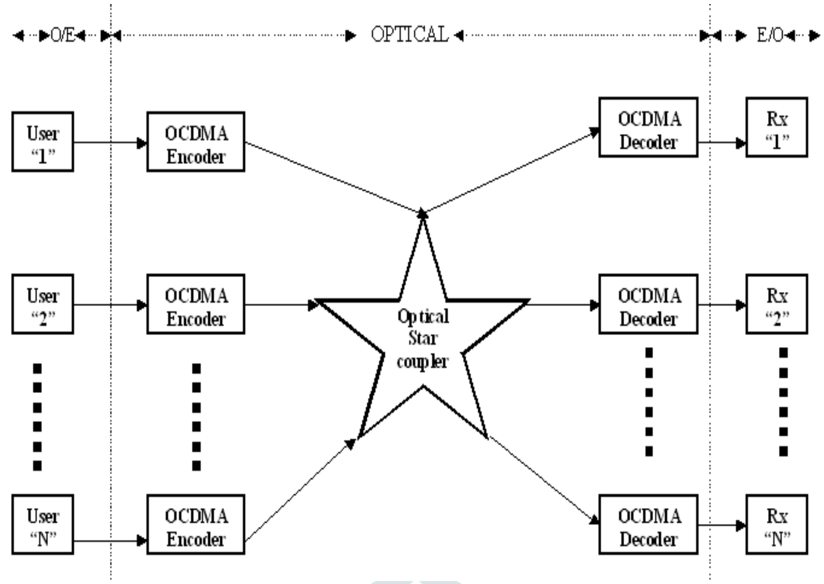

Fig. 1: OCDMA Network

The information available with different users is electrical in nature. Optical encoder converts electrical signal into optical sequences with the help of LED or LASERs. Optical coupler collects light from all the users and distributes resultant signal to all the decoders/receivers. Each optical receiver uses optical filter to isolate the desired signal from other undesired signals [6].

II. OPTICAL CODES

The effective CDMA system implementation requires excellent autocorrelation and cross correlation properties of code sequences. In wireless communication systems, we implement RF CDMA systems with bipolar sequences with +1 and -1 values. However, in optical system the direct application of the bipolar codes is not possible due to non-negative nature of the light. Thus, it requires unipolar sequences consisting of 0 and 1 values.

Thus, optical codes are comprised of sequences of 0 and 1with excellent self-correlation and cross-correlation properties. These codes require high self-correlation value and low cross correlation value between two sequences as they helps in signal detection less interference, respectively. The main objective of OCDMA is to abstract original data from address code in the presence of other similar users. Thus, the OOC must satisfy the three main conditions:

(1) The codeword's non-shifted autocorrelation must be as large as possible to ensure the signal detection possible under noise.
(2) The codeword's autocorrelation must be much as less as to ensure the minimum output at the receiver side especially when it is not synchronized with the transmitter [3].

III. PRIME CODE

Prime codes were introduced firstly by Prucnal in 1986. This code sequence is defined as (0,1) valued codes with low cross correlation e by reducing chances of coincidence between users to obtain good orthogonal conditions in multiuser positive environment. These codes can be successfully implemented using optical delay lines. The codes sequence of length (N) equals to P2 is defined by the Galois field

GF(P) = {0,1,2,3,4,……..,(P-2),(P-1) }

By multiplying every element j of GF(P), a Prime Sequence S_X = (Sx0, Sx1, Sx2,……….., Sxj,……, Sx(P-1)) is developed as explained below

J \ x	0	1	2	3	4
0	0	0	0	0	0
1	0	1	2	3	4
2	0	2	4	1	3
3	0	3	1	4	2
4	0	4	3	2	1

Since; Sx = (Sx0, Sx1, Sx2,……….., Sxj,……, Sx(P-1))

Therefore,

S0 = {S00, S01, S02, S03, S04}

S2 = {S20, S21, S22, S23, S24}

S4 = {S40, S41, S42, S43, S44}

From table above, the entries would become

S0 = {0 0 0 0 0}

S2 = {0 2 4 1 3}

S4 = {0 4 3 2 1}

Now, these codes can be converted into binary codes comprises of 0's and 1's.

x	i	code	Code Sequences						
	0123456								
0	0000000	C0	1000000	1000000	1000000	1000000	1000000	1000000	1000000
2	0246135	C2	1000000	0010000	0000100	0000001	0100000	0001000	0000010
4	0415263	C4	1000000	0000100	0100000	0000010	0010000	0000001	0001000
6	0654321	C6	1000000	0000001	0000010	0000100	0001000	0010000	0100000

IV. 2n PRIME CODES

2n Prime codes are the collection of binary N-tuples of weight 2n. To generate such codes for any positive integer n, we have integers like x, y, and z such that

(i) $X \neq Y$

(ii) $0 \leq X \leq 2N-2$

(iii) $0 \leq Y \leq 2N-2$, and

(iv) $1 \leq Z \leq N-1$.

The Galois field for prime number P=11 is as shown in table below

i\j	0	1	2	3	4	5	6	7	8	9	10
0	0	0	0	0	0	0	0	0	0	0	0
2	0	2	4	6	8	10	1	3	5	7	9
4	0	4	8	1	5	9	2	6	10	3	7
6	0	6	1	7	2	8	3	9	4	10	5
8	0	8	5	2	10	7	4	1	9	6	3
10	0	10	9	8	7	6	5	4	3	2	1

V. MODIFIED PRIME CODES

To accommodate large number of users, new P3-P2+P code sequence can be generated by the timely shifting of CDMA sequences. The value of cross correlation between the codes can be minimized to meet the requirements of large number of users. The elements of the prime sequence Sx= (Sxt0, Sxt1, Sxt2,…). The Prime sequence $S_{x,t}$ can be represented as

Cx,t = (Cxt0, ,Cxt1 ,Cxt2 ,……………,Cxt(P-1))

Cxti = {1 for i= Sxtj+jP j=0,1,2,……..,P-1}

{0 otherwise }

The value of auto & cross correlation considered here is 2.

VI. RESULTS AND DISCUSSION

Different codes have been proposed time to time for optical CDMA. Here, the comparative study has been made for 1- dimensional OOC for Incoherent OCDMA system. These codes are (i) Basic Prime Code (ii) 2n Prime Code, and (iii) Modified Prime Code. The codes have been analyzed for various code and system parameter such as code length, code cardinality, auto & cross correlation values, number of subscribers, constrained and unconstrained sequence length using different kinds of threshold detectors.

Table II: Comparison of Prime Codes

Prime Code					2^n Code					MPC			
P	w	F	Lp (dB)	BER	n	w	F	Lp (dB)	BER	w	F	Lp (dB)	BER
11	11	121	20.8	6.19X10-4	2	4	88	12.0	3.20X10-2	8	174	18.1	6.5X10-3
13	13	169	22.3	2.4 X10-4	2	4	104	12.0	1.64X10-3	8	206	18.1	7.3X10-3
19	19	361	25.6	1.60X10-5	3	8	304	18.1	1.63X10-4	12	454	21.5	1.12X10-4
23	23	529	27.3	2.64X10-6	3	8	368	18.1	3.45X10-5	14	642	22.9	5.43X10-5
43	43	1849	32.7	3.62X10-10	4	16	1376	24.0	2.13X10-8	19	1632	25.6	4.57X10-6
47	47	2209	33.4	6.20X10-11	4	16	1504	24.0	1.15X10-9	20	1878	26.0	1.89X10-7
51	51	2601	34.1	1.066X10-11	4	16	1632	24.0	3.14X10-10	21	2140	26.4	0.64X10-8
53	53	2809	34.5	4.42X10-12	5	32	3392	30.1	6.05X10-11	22	2330	26.8	1.34X10-8
59	59	3481	35.4	5.10X10-13	5	32	3776	30.1	4.43X10-12	24	2830	27.6	0.7X10-9
71	71	5041	37.0	1.64X10-15	5	32	4544	30.1	7.04X10-14	26	3690	28.3	0.3X10-9
127	127	16129	42.0	4.10X10-26	6	64	16256	36.1	1.18X10-18	26	6602	28.3	0.2X10-9

It has been observed that using incoherent optical signal processing and optimum optical codes, more number of subscribers can be accommodated as compare to the conventional system. In this chapter, we have considered three variants of prime codes. These are (i) Basic Prime Code (ii) 2n Prime Code & (iii) Modified Prime Code. The comparison is done for various code & system parameters such as code cardinality, code weight, power losses incurred and BER. The parameters used for comparison are (i) Prime Number (P) (ii) Code Weight (w) (iii) Length of code sequence (F) (iv) Power losses in dB (L_P),and (v) Bit Error Rate.

It is clear from comparison table II that in case of basic prime codes, more is the value of prime number P, more will be the code weight. It increases number of ones in code sequence, thus the effective power from each user, SNR improves and therefore reduces BER significantly. However, this improvement comes with price of increased hardware complexity and significant power loss. Here, while simulation, with increase in code weight increase in input power and therefore, introduction of optical nonlinearities have been ignored.it can be seen from table with an increase in prime number BER also increasing,

For 2n prime code the code weight could be any value in terms of power of 2. It is clear from table above that almost same value of BER could be achieved using lesser code weight and with lesser power penalty. In addition to this significant of sequence length could be seen in comparison with basic prime could which reduce the requirement of wide band laser sources or very narrow bandwidth filter requirement. Similar observations come for modified prime codes, the large number of subscribers can have unique codes with permissible values of BER that is 10^{-9} with small code sequences and lesser power penalties. More improvements can be made by choosing appropriate threshold detector device. Under very noisy channel conditions, Quality of service can be improved by using optical hard limiter where as if QOS is not a constrained large number of subscribers can be assigned with an adequate network performance using optical soft limiter.

XI. CONCLUSION AND FUTURE SCOPE

In this paper, 1 D prime codes have been studied in detail. The conclusion has been drawn that codes with more number of ones make signal detection easy due to their high auto correlation value. However, they impose serious power penalty on a system. Under very noisy channel conditions, Quality of service can be improved by using optical hard limiter where as if QOS is not a constrained more number of subscribers can be accommodated with an adequate network performance using optical soft limiter.

The idea of can further extended for examining the system performance for 2 and 3- dimensional optical prime codes. Moreover, the different modulation techniques can also be analyzed for the same system. It is also possible to design and analyze theoretically using simulation and design software tools like MATLAB and OPTSIM collectively for different number of users with variable dimension tools for variable data rates.

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